NNG05EA01C,

Hubble Robotic Vehicle

Deorbit Module

CONTRACT

(Sept. 24, 2004)

OMB APPROVAL #: 2700-0042

AWARD/CONTRACT

1. THIS CONTRACT IS A RATED ORDER UNDER DPAS (15 CFR 350) ⇒ RATING DO-C9

PAGE 1 OF PAGES 52

2. CONTRACT NO. (*Proc. Inst. Ident.*) NO. **NNG05EA01C**

3. EFFECTIVE DATE **October 1, 2004**

4. REQUISITION/PURCHASE REQUEST/PROJECT NO.

5. ISSUED BY: CODE 210.S

NASA Goddard Space Flight Center
Space Sciences Procurement Office
Greenbelt, MD 20771

6. ADMINISTERED BY (*If other than item 5*) CODE

7. NAME AND ADDRESS OF CONTRACTOR (No., street, city, county, State and ZIP

Lockheed Martin Space Systems Company
12257 South Wadsworth Blvd.
Littleton, CO 80125

CODE ONWP5
CAGE 604236
DUNS 878230135

FACILITY CODE

8. DELIVERY ☐ FOB ORIGIN ☐ OTHER

9. DISCOUNT FOR PROMPT PAYMENT N/A

10. SUBMIT INVOICES (*4 copies unless other-wise specified*) TO THE ADDRESS SHOWN IN: ⇒ ITEM 12

11. SHIP TO/MARK FOR CODE

See Section F.3 for additional information

12. PAYMENT WILL BE MADE BY: CODE 155

Cost and Commercial Accounts Department
Code 155
Goddard Space Flight Center
Greenbelt, Maryland 20771

13. AUTHORITY FOR USING OTHER THAN FULL AND OPEN N/A

☐ 10 U.S.C. 2304(c) ☐ 41 U.S.C. 253(c)

14. ACCOUNTING AND APPROPRIATION DATA

PPC: BX BCN:GDJ See Section B.5 for additional information

15A. ITEM NO.	15B. SUPPLIES/SERVICES	15C. QTY	15D. UNIT	15E. UNIT PRICE	15F. AMOUNT
	Hubble Robotic Vehicle Deorbit Module				
				15G. TOTAL AMOUNT OF CONTRACT ⇒	**$330,578,914**

16. TABLE OF CONTENTS

CONTRACTING OFFICER WILL COMPLETE ITEM 17 OR 18 AS APPLICABLE

17 ☐ CONTRACTOR'S NEGOTIATED AGREEMENT (*Contractor is required to sign this document and return ______ copies to issuing office.*)

Contractor agrees to furnish and deliver all items or perform all the services set forth or otherwise identified above and on any continuation sheets for the consideration stated herein. The rights and obligations of the parties to this contract shall be subject to and governed by the following documents (s) this award/contract, (b) the solicitation, if any, and (c) such provisions, representations, certifications, and specifications, as are attached or incorporated by reference herein. (*Attachments are listed herein.*)

18. ☒ AWARD (*Contractor is not required to sign this document.*) Your offer on Solicitation Number **NNG04461779R(HRVDM)**

including the additions or changes made by you which additions or changes are set forth in full above, is hereby accepted as to the items listed above and on any continuation sheets. This award consummates the contract which consists of the following documents: (a) the Government's solicitation and your offer, and (b) this award/contract. No further contractual document is necessary.

19A. NAME AND TITLE OF SIGNER (*Type or print*)

20A. NAME OF CONTRACTING OFFICER
Carlos R. McKenzie – Contracting Officer

19B. NAME OF CONTRACTOR

BY ______________________
(*Signature of person authorized to sign*)

19C. DATE SIGNED

20B. UNITED STATES OF AMERICA

BY ______________________
(*Signature of Contracting Officer*)

20C. DATE SIGNED
SEP 24 2004

INDEX OF CLAUSES FOR NNG05EA01C

INDEX OF CLAUSES FOR NNG05EA01C

SECTION H--SPECIAL CONTRACT REQUIREMENTS

SECTION I--CONTRACT CLAUSES

SECTION J--LIST OF ATTACHMENTS

SECTION B OF NNG05EA01C
SUPPLIES OR SERVICES AND PRICES/COSTS

B. 1 DELIVERABLE REQUIREMENTS (GSFC 52.211-90) (OCT 1988)

The Contractor shall provide the personnel, materials, equipment and facilities, except as otherwise provided in the contract, necessary to provide the items described below and as described under Clause J.1 entitled "List of Attachments".

ITEM	DESCRIPTION	REFERENCE/ QTY	DELIVERY DATE	SHIPPING CLASS
1	SOW Requirements	C.1& J.1	See C.1& J.1	N/A
2	Deliverable Items List and Schedule (DILS)/Data Requirements Document (DRD)/Mission Assurance Requirements (MAR)	C.4 & J.1	As required	N/A
3	DoD Industrial Plant Equipment (Form DD 1419)	NFS 1852.245-70 NFS 1852.245-71	See G.1	N/A
4	NASA Property in the Custody of Contractors (NASA Form 1018)	NFS 1852.245-73	See G.1	N/A
5	Financial Management Reports	G.2	See G.2	N/A
6	New Technology Reports	G.7	See G.7	N/A
7	Small Business Subcontracting Reports	H.8/NFS 1852.219-75	H.8/NFS 1852.219-75	N/A
8	Material Safety Data Sheets	See Clause I.5	See Clause I.5	IV
9	Notification of Noncompliance with Safety Standards & Quarterly Health and Safety Reports	H.1& H.10	See NFS 1852.223-70 & H.10	N/A
10	System Requirements Review (SRR)	C.4 & J.1	10/2004	N/A
11	Preliminary Design Review (PDR)	C.4 & J.1	11/2004	N/A
12	Critical Design Review (CDR)	C.4 & J.1	06/2005	N/A
13	Mission Operations Review (MOR)	C.4 & J.1	09/2005	N/A
14	Test Readiness Review (TRR)	C.4 & J.1	09/2006	N/A
15	Operations Readiness Review (ORR)	C.4 & J.1	12/2006	N/A
16	Pre-Shipment Review (PSR)	C.4 & J.1	03/2007	N/A
17	Final Report	C.3	Thirty (30) days after completion of Disposal	N/A
18	HRV Deorbit Module (For Mission Level I&T)	1	Launch minus Nine (9) Months	I
19	Acceptance of HRV Deorbit Module after in-Orbit Checkout	1	Launch plus 90 days	N/A
20	HST/HRV Deorbit Module Disposal	C.1 & J.1	Launch plus Disposal**	N/A

21	HRV Deorbit Module Special Studies	C.5 & H.15	Award thru Launch	N/A
22	HRV Deorbit Module Mission Operation Tasks	C.6 & H.15	Launch thru Disposal	N/A
23	Shipping Containers, Handling & Integration Equipment and Fixtures	1 Set/C.1 & J.1	With Item 18	III
24	Common Components	H.5, C1 & J.1	As required	I
25	Shipping Containers, Handling & Integration Equipment and Fixtures	1 Set/C.1 & J.1	With Item 24	III
26	RESERVED	N/A	N/A	N/A
27	RESERVED	N/A	N/A	N/A
28	RESERVED	N/A	N/A	N/A
29	Software Development & Validation Facility (SDVF) including the GSE Software. (SDVF deliver in place)	1/C.1 & J.1	Twelve (12) Months ACA	II
30	Software Development & Validation Facility (SDVF) including the GSE Software.(FSW Validation & Maintenance Facility deliver to GSFC)	1/C.1 & J.1	Twelve (12) Months ACA	II
31	Software Development & Validation Facility (SDVF) including the GSE Software (HRV Training Simulator deliver to GSFC)	1/C.1 & J.1	Twelve (12) Months ACA	II
32	Ground System Validation Simulator	2/C.1 & J.1	Twelve (12) Months ACA	I
33	HRV DM Ground Test System. Hardware & Software	2 Sets/C.1 & J.1	Twelve (12) Months ACA	I
34	HRV DM Flight Software Source Code	C.1 & J.1	With item 18	I
36	Handling Fixtures, Mechanical Ground Support Equipment, Electrical GSE and Test Software associated with the HRV DM.	C.1 & J.1	With item 18	III
37	Engineering Test Units for each Navigation Sensor	C.1 & J.1	3 months after item 12	II
38	Engineering Test relative navigation software source code	C.1 & J.1	With item 12	II
39	Software Development, Validation and Maintenance Environment	C.1 & J.1	Twelve (12) Months ACA	II
40	HRV DM Electrical Interface Simulator	C.1 & J.1	Launch minus 16 months	I
41	Thermal – Mechanical HRV DM Simulator	C.1 & J.1	Launch minus 15 months	I
42	DMGTS Application Program Interfaces	C.1 & J.1	With item 12	II
43	DMGTS Trainer	C.1 & J.1	With item 12	III

*ACA = After Contract Award
** Disposal = To be determined depending on the disposal method proposed by the contractor. However if the contractor proposes to utilize the alternate method of HST disposal, in accordance with NPD 8710.3B (perigee > 2,500 km, Apogee < 35,288 km) the disposal shall be accomplished within five years after initiation of the disposal process. The completion of the disposal process shall be no more

than twelve (12) years after launch. This clause may be modified after contract award to reflect the actual disposal method of the selected offeror.

B. 2 ESTIMATED COST INCREASES (GSFC 52.232-94) (SEP 1998)

(a) The requirements of this clause are in conjunction with the Limitation of Cost clause or the Limitation of Funds clause of this contract.

(b) The Contractor shall notify the Contracting Officer in writing when the Contractor has reason to believe that the total cost for performance of this contract, exclusive of any fee, will be either greater or substantially less than the total estimated cost stated in this contract. Notification shall not be delayed pending preparation of a proposal.

(c) A proposal is required to support a request for an increase in the estimated cost of the contract. The proposal should be submitted as soon as possible after the above notification but no later than 115 days before the incurred costs are expected to exceed the estimated cost. This will allow adequate time for the Government to evaluate the proposal and to mutually establish any increase in estimated cost with the Contractor.

(d)(1) The proposal shall be submitted in the following format unless some other format is directed or approved by the Contracting Officer:

Incurred costs to date
Projected cost to completion
Total cost at completion
Current negotiated estimated cost
Requested increase in estimated cost

(2) The "projected cost to completion" shall consist of the following "other than cost or pricing data" unless the Contracting Officer requests or approves the submittal of a greater or lesser amount of information:

(i) Elements of cost with supporting detail for estimated direct labor hours, direct and indirect rates, materials and subcontracts, and other elements.

(ii) Supporting explanation for the increases and projections, sufficient for the Government to understand the reasons for the increased estimated cost.

(End of clause)

B. 3 PERFORMANCE INCENTIVE (1852.216-88) (JAN 1997)

(a) A performance incentive applies to the following hardware item(s) delivered under this contract:

Item 18 "Deorbit Module" – Performance of the HRV Deorbit Module will be measured by the following performance requirements: (1) Capture/docking with the Hubble Space Telescope (HST), (2) Robotic Servicing Support (3) Ejection of the DM, (4) HST Life augmentation functions and housekeeping, and 5) Safe disposal of the HST/DM combined spacecraft.

The performance incentive will measure the performance of those items against the salient hardware performance requirement, called "unit(s) of measurement," e.g., months in service or amount of data transmitted, identified below. The performance incentive becomes effective when the hardware is put into service. It includes a standard performance level, a positive incentive, and a negative incentive, which are described in this clause.

(b) Standard performance level. At the standard performance level, the Contractor has met the contract requirement for the unit of measurement. Neither positive nor negative incentives apply when this level is achieved but not exceeded. The standard performance level for each of the hardware items is established as follows:

a. The HRVDM shall capture/dock with the HST.
b. The HRVDM shall maintain supervisory control functions during HST servicing.
c. The HRVDM shall perform mechanical detachment of the EM from the DM.
d. The HRVDM performs its HST life augmentation functions through the hardware that resides within it (batteries and ECU's) and housekeeping for five (5) years.
e. The HRVDM shall provide the HST with a controlled reentry or other disposal capability at end-of-mission in accordance with NPD 8710.3B.**

(c) Positive incentive. The Contractor earns a separate positive incentive amount for each hardware item listed in paragraph (a) of this clause when the standard performance level for that item is exceeded. The amount earned for each item varies with the units of measurement achieved, up to a maximum positive performance incentive amount of $21,488,101. The units of measurement and the incentive amounts associated with achieving each unit are shown below:

Item	Description	Percentage*	Amount
a.	The HRV DM shall capture/dock within specified fuel budgets.	30.0%	$ TBD
b.	The HRV DM shall maintain supervisory control functions during HST servicing in accordance with Attachment B Section 6.3.4.4 entitled "Servicing Activities", without anomalies.	10.0%	$ TBD
c	The HRV DM successfully ejects the HRV EM after servicing in accordance with Attachment B Section 6.3.5 entitled "EM Ejection", with the primary system.	20.0%	$ TBD
d.	The HRV DM performs its HST life augmentation for more than 5 years after in-orbit checkout.	15.00%	$ TBD
e.	The HRV DM successfully disposes of the HST at end-of-mission, in accordance with NPD 8710.3B, and (Deorbit) safely deorbits with reentry dispersion area no larger that 80% of the allowed dispersion area, or (boost) achieves required parking orbit with perigee of at least 2600 km.**	25.00%	$ TBD

* Percentage is based on amount established under (c) above.

(d) Negative incentive. The Contractor will pay to the Government a negative incentive amount for each hardware item that fails to achieve the standard performance level. The amount to be paid for each item varies with the units of measurement achieved, up to the maximum negative incentive amount of $_Total Award Fee Earned. The units of measurement and the incentive amounts associated with achieving each unit are shown below:

Item	Description	Percentage*	Amount
a.	The HRVDM fails to capture/dock with HST	100.0%	TBD
b	Any failure of the DM to maintain supervisory control functions which results in damage to HST or inability to complete the servicing mission.	50.0%	$ TBD
c	The HRVDM fails to safely eject the EM upon end of servicing***	100.00%	$ TBD
d	The HRVDM performs its HST life augmentation for less than 5 years after in-orbit checkout.	15.00%	$ TBD
e	The HRVDM does not provide controlled reentry or otherwise dispose of the HST upon end of mission in accordance with NPD 8710.3B**	100.00%	$ TBD

* Percentage is based on amount established under (d) above.

** This clause may be modified after contract award to reflect the actual disposal method of the selected offeror.

***For this purpose, safe ejection is considered an ejection of the EM that causes no damage to the HST or the DM, and which permits a controlled reentry of the EM.

(e) The final calculation of positive or negative performance incentive amounts shall be done when performance (as defined by the unit of measurement) ceases or when the maximum positive incentive is reached.

(1) When the Contracting Officer determines that the performance level achieved fell below the standard performance level, the Contractor will either pay the amount due the Government or credit the next payment voucher for the amount due, as directed by the Contracting Officer.

(2) When the performance level exceeds the standard level, the Contractor may request payment of the incentive amount associated with a given level of performance, provided that such payments shall not be more frequent than monthly. When performance ceases or the maximum positive incentive is reached, the Government shall calculate the final performance incentive earned and unpaid and promptly remit it to the contractor.

(f) If performance cannot be demonstrated, through no fault of the Contractor, within **See table below** after the date of hardware acceptance by the Government, the Contractor will be paid **Seventy –five (75) percent** of the maximum performance incentive.

Item	Incentivize Event	Period of time
a.	Capture/Docking with HST	Twelve (12) months after Launch

b.	Supervisory control functions	Twelve (12) months after Capture/Docking
c.	The HRV DM Ejection of the HRV EM	Twelve (12) months after completion of servicing
d.	HST life augmentation	Twelve (12) months after ejection
e.	HST/DM Disposal	Twelve (12) months after planned initiation of disposal

(g) The decisions made as to the amount(s) of positive or negative incentives are subject to the Disputes clause.

(End of clause)

B. 4 ESTIMATED COST AND AWARD FEE (18-52.216-85) (SEPTEMBER 1993)--ALTERNATE I (SEPTEMBER 1993)

The estimated cost of this contract is **$287,602,712.** The maximum available award fee, excluding base fee, if any, is **$21,488,101.** The base fee is **$ 0** Total estimated cost, base fee, and maximum award fee are **$309,090,813.** The maximum positive performance incentive is **$21,488,101.** The maximum negative performance incentive is $**21,488,101.**

(End of clause)

B. 5 CONTRACT FUNDING (1852.232-81) (JUN 1990)

(a) For purposes of payment of cost, exclusive of fee, in accordance with the Limitation of Funds clause, the total amount allotted by the Government to this contract is **$5,320,000** This allotment is for **Effort required under the contract** and covers the following estimated period of performance: **Until funds are exhausted**.

(b) An additional amount of **$399,000** is obligated under this contract for payment of fee.

PR No. 4200085195 Total Obligated Amount: $5,719,000

(End of clause)

SECTION C OF NNG05EA01C
DESCRIPTION/SPECIFICATIONS/WORK STATEMENT

C. 1 SCOPE OF WORK (GSFC 52.211-91) (FEB 1991)

The Contractor shall provide the personnel, materials, equipment and facilities, except as otherwise provided in this contract, necessary to furnish the items specified in Section B of this contract in accordance with Clause J.1, List of Attachments.

(End of clause)

C. 2 LIMITED RIGHTS DATA OR RESTRICTED COMPUTER SOFTWARE (GSFC 52.227-90) (OCT 1988)

In accordance with the Rights in Data - General clause of this contract, the following limited rights data and restricted computer software shall be delivered in accordance with the delivery requirements for data and/or software, specified elsewhere in this contract:

(End of clause)

C. 3 FINAL SCIENTIFIC AND TECHNICAL REPORTS (1852.235-73)(FEB 2003)

(a) The Contractor shall submit to the Contracting Officer a final report that summarizes the results of the entire contract, including recommendations and conclusions based on the experience and results obtained. The final report should include tables, graphs, diagrams, curves, sketches, photographs, and drawings in sufficient detail to explain comprehensively the results achieved under the contract.

(b) The final report shall be of a quality suitable for publication and shall follow the formatting and stylistic guidelines contained in NPG 2200.2A, Guidelines for Documentation, Approval, and Dissemination of NASA Scientific and Technical Information. Electronic formats for submission of reports should be used to the maximum extent practical. Before electronically submitting reports containing scientific and technical information (STI) that is export-controlled or limited or restricted, contact the Contracting Officer to determine the requirements to electronically transmit these forms of STI. If appropriate electronic safeguards are not available at the time of submission, a paper copy or a CD-ROM of the report shall be required. Information regarding appropriate electronic formats for final reports is available at http://www.sti.nasa.gov under "Publish STI – Electronic File Formats."

(c) The last page of the final report shall be a completed Standard Form (SF) 298, Report Documentation Page.

(d) In addition to the final report submitted to the Contracting Officer, the Contractor shall concurrently provide to the Center STI/Publication Manager and the NASA Center for AeroSpace Information (CASI) a copy of the letter transmitting the final report to the Contracting Officer. The copy of the letter shall be submitted to CASI at the following address:

Center for AeroSpace Information (CASI)
Attn: Acquisitions Collections Development Specialist
7121 Standard Drive
Hanover, Maryland 21076-1320

(e) In accordance with paragraph (d) of the Rights in Data --General clause (52.227-14) of this contract, the Contractor may publish, or otherwise disseminate, data produced during the performance of this contract, including data contained in the final report, and any additional reports required by 1852.235-74 when included in the contract, without prior review by NASA. The Contractor is responsible for reviewing publication or dissemination of the data for conformance with laws and regulations governing its distribution, including intellectual property rights, export control, national security and other requirements, and to the extent the contractor receives or is given access to data necessary for the performance of the contract which contain restrictive markings, for complying with such restrictive markings. Should the Contractor seek to publish or otherwise disseminate the final report, or any additional reports required by 1852.235-74 if applicable, as delivered to NASA under this contract, the Contractor may do so once NASA has completed its document availability authorization review, and availability of the report has been determined.

(End of clause)

C.4 DELIVERABLE ITEMS LIST AND SCHEDULE (DILS)/DATA REQUIREMENTS DOCUMENT (DRD)/MISSION ASSURANCE REQUIREMENTS (MAR)

(a) The Contractor shall provide the items as described under Attachment C, Attachment D and Attachment E entitled "Deliverable Items List and Schedule (DILS)" and "Data Requirements Document" and Mission Assurance Requirements (MAR), respectively. The above attachments identifies the distribution, format, level of review, organization, delivery media, quantities of the data items to be provided by the Contractor. All documents shall be accompanied by a cover letter or email note (if delivered electronically) from authorized contract representative officially stating delivery in compliance with the contract.

(b) Submission: The Contractor shall submit the reports required by this clause as follows:

Address	**Address**
210.S/Contracting Officer*	NASA, Goddard Space Flight Center Code 210.S, Mail Code 445, Greenbelt, MD 20771
NASA/Contracting Officer's Technical Representative (COTR)	NASA, Goddard Space Flight Center Code 445, Greenbelt, MD 20771
Configuration Management Office (CMO)	NASA, Goddard Space Flight Center HST Project/ Code 445 Greenbelt, MD 20771

* Copy of letter of transmittal only

(c) Submission dates. Monthly and quarterly reports shall be submitted by the 15th day of the month following the month or quarter being reported. If the contract is awarded beyond the middle of a month, the first monthly report shall cover the period from award until the end of the following month. No monthly report need be submitted for the third month of contract effort for which a quarterly report is required. No quarterly report need be submitted for the final three months of contract effort since that period will be covered in the final report. The final report shall be submitted within thirty (30) calendar days after the completion of the effort under the contract.

(END OF TEXT)

C. 5 LEVEL-OF-EFFORT FOR SPECIAL STUDIES

(a) During the term of the contract, the Contractor may provide level-of-effort direct labor hours for special studies (see Statement of Work Section 1.8) as ordered by task orders (see Clause H.15). The quantity of hours shall not exceed **31,200** direct labor hours. The Government reserves the right to increase the quantity of direct labor hours by no more than 20%, in accordance with the changes clause.

(b) "Direct labor hours" are productive hours expended by Contractor personnel performing work under this contract that are charged as direct labor under the Contractor's established accounting policy and procedures. The terms do not include sick leave, vacation leave, holiday leave, military leave, or any type of administrative leave but does include direct labor hours provided under level-of-effort subcontracts.

(c) The Contractor is not authorized to exceed the direct labor hours specified in paragraph (a) of this clause.

(d) Any unused level-of-effort direct labor hours under this clause may be added to the available hours under contract clause C.6.

(END OF TEXT)

C. 6 LEVEL-OF-EFFORT FOR MISSION OPERATIONS

(a) During the term of the contract, the Contractor may provide level-of-effort direct labor hours for Mission Operations (see Statement of Work Section 14.0) as ordered by task orders (see Clause H.15). The quantity of hours shall not exceed **60,000 direct labor hours**. The direct labor hours are broken down as follows: 30,000 hrs for the period from Launch thru HST end of mission; in addition, 5,000 hours per year thereafter until completion of controlled reentry or disposal not to exceed a total of 30,000 hrs. The specific quantity of hours from HST end of mission through controlled reentry or disposal will be determined by the length of time for the disposal method proposed by the offeror. This clause may be adjusted after award as necessary to be consistent with the selected offeror's approach.

The Government reserves the right to increase the quantity of direct labor hours by no more than 20% in accordance with the changes clause.

(b) "Direct labor hours" are productive hours expended by Contractor personnel performing work under this contract that are charged as direct labor under the Contractor's established accounting policy and procedures. The terms do not include sick leave, vacation leave, holiday leave, military leave, or any type of administrative leave but does include direct labor hours provided under level-of-effort subcontracts.

(c) The Contractor is not authorized to exceed the direct labor hours specified in paragraph (a) of this clause.

(END OF TEXT)

SECTION D OF NNG05EA01C
PACKAGING AND MARKING

D. 1 PACKAGING, HANDLING, AND TRANSPORTATION (1852.211-70) (JUNE 2000)

(a) The Contractor shall comply with NPR6000.1F, "Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components", dated April 26, 1999, as may be supplemented by the statement of work or specifications of this contract, for all items designated as Class I, II, or III.

(b) The Contractor's packaging, handling, and transportation procedures may be used, in whole or in part, subject to the written approval of the Contracting Officer, provided--

(1) The Contractor's procedures are not in conflict with any requirements of this contract, and

(2) The requirements of this contract shall take precedence in the event of any conflict with the Contractor's procedures.

(c) The Contractor must place the requirements of this clause in all subcontracts for items that will become components of deliverable Class I, II, or III items.

(End of clause)

SECTION E OF NNG05EA01C
INSPECTION AND ACCEPTANCE

E. 1 SECTION E CLAUSES INCORPORATED BY REFERENCE

(52.246-8) INSPECTION OF RESEARCH AND DEVELOPMENT--COST REIMBURSEMENT (MAY 2001)

(End of By Reference Section)

E. 2 ACCEPTANCE--SINGLE LOCATION

The Contracting Officer or authorized representative will accomplish acceptance at NASA/Goddard Space Flight Center, Greenbelt, MD 20771 for all items under contract clause B.1 except for items 18 & 19. For the purpose of this clause, the Contracting Officer's Technical Representative named in this contract is the authorized representative. The Contracting Officer reserves the right to unilaterally designate a different Government agent as the authorized representative. The Contractor will be notified by a written notice or by a copy of the delegation of authority if different representative is designated.

(End of clause)

E. 3 MATERIAL INSPECTION AND RECEIVING REPORT NOT REQUIRED (GSFC 52.246-94) (APR 1989)

NASA FAR Supplement clause 18-52.246-72 of this contract requires the furnishing of a Material Inspection and Receiving Report (MIRR) (DD Form 250 series) at the time of each delivery under this contract. However, a MIRR is not required for the following deliverable items:

ITEM	DESCRIPTION
1	SOW Requirements
2	Deliverable Items List and Schedule (DILS)/Data Requirements Document (DRD)/ Mission Assurance Requirements (MAR)
3	DoD Industrial Plant Equipment (Form DD 1419)
4	NASA Property in the Custody of Contractors (NASA Form 1018)
5	Financial Management Reports
6	New Technology Reports
7	Small Business Subcontracting Reports
8	Material Safety Data Sheets
9	Notification of Noncompliance with Safety Standards & Quarterly Health and Safety Reports
10	System Requirements Review (SRR)
11	Preliminary Design Review (PDR)
12	Critical Design Review (CDR)

13	Mission Operations Review (MOR)
14	Test Readiness Review (TRR)
15	Operations Readiness Review (ORR)
16	Pre-Shipment Review (PSR)
17	Final Report

(End of clause)

E. 4 INSPECTION SYSTEM (SUBCONTRACTS) (GSFC 52.246-100) (JULY 2000)

In performance of this contract, the Contractor shall impose inspection system requirements on subcontractors and suppliers to ensure the required quality of supplies or services. Monitoring of the Contractor's system for inspecting subcontractors will be accomplished through the combined efforts of NASA/GSFC personnel and the delegated Government agency. The authority and responsibility of the delegated agency will be defined in a letter of contract administration delegation.

(End of clause)

E. 5 INSPECTION SYSTEM RECORDS (GSFC 52.246-102) (OCT 1988)

The Contractor shall maintain records evidencing inspections in accordance with the Inspection clause of this contract for seven (7) years after delivery of all items and/or completion of all services called for by the contract.

(End of clause)

E. 6 HIGHER-LEVEL CONTRACT QUALITY REQUIREMENT (52.246-11) (FEB 1999)

The Contractor shall comply with the higher-level quality standard contained in Attachment E, "Mission Assurance Requirements."

(End of clause)

E. 7 GOVERNMENT CONTRACT QUALITY ASSURANCE FUNCTIONS (1852.246-71) (OCT 1988)

In accordance with the Inspection clause of this contract, the Government intends to perform the following functions at the locations indicated:

NO	QUALITY ASSURANCE ITEM	QA FUNCTION	LOCATION

01	Testing	Monitoring and Witnessing by Government QA Representatives	Contractor and Subcontractor Facilities
02	Electronic Assemblies	Inspection of electronic assemblies prior to their installation	Contractor and Subcontractor Facilities
03	Mechanical Assemblies	Inspection of mechanical assemblies prior to assembly into next higher level of assembly	Contractor and Subcontractor Facilities
04	Manufacturing Process	Monitoring of various manufacturing processes for compliance	Contractor and Subcontractor Facilities
05	Procedural and Requirements Compliance	Surveys, audits, and monitoring of compliance to procedures and requirements	Contractor and Subcontractor Facilities

(End of clause)

E. 8 MATERIAL INSPECTION AND RECEIVING REPORT (1852.246-72) (AUG 2003)

(a) At the time of each delivery to the Government under this contract, the Contractor shall furnish a Material Inspection and Receiving Report (DD Form 250 series) prepared in an original copy and sufficient other copies to accomplish the following distribution:

(1) Via mail and marked "Advance Copy", one copy each to the Contracting Officer, the Contracting Officer's Technical Representative (if designated in the contract), and to the cognizant Administrative Contracting Officer, if any.

(2) Via mail, the original and 1 copy (unfolded) to the shipment address (delivery point) specified in Section F of this contract. Mark the exterior of the envelope "CONTAINS DD FORM 250". This must arrive prior to the shipment.

(3) With shipment in waterproof envelope (one copy) for the consignee.

(4) If the shipment address is not directly to the Goddard Space Flight Center (Greenbelt) or Goddard Space Flight Center (Wallops) central receiving areas, then one copy of the DD Form 250 must be provided (via mail) to one on the following addresses depending upon whether this contract is with GSFC Greenbelt or GSFC Wallops:

Receiving and Inspection (Code 239), Goddard Space Flight Center, Greenbelt, MD 20771.

Receiving and Inspection (Bldg. F16), Wallops Flight Facility, Wallops Island VA 23337.

(b) The Contractor shall prepare the DD Form 250 in accordance with NASA FAR Supplement 18-46.6. The Contractor shall enclose the copies of the DD Form 250 in the package or seal them in a waterproof envelope, which shall be securely attached to the exterior of the package in the most protected location.

(c) When more than one package is involved in a shipment, the Contractor shall list on the DD Form 250, as additional information, the quantity of packages and the package numbers. The Contractor shall forward the DD Form 250 with the lowest numbered package of the shipment and print the words "CONTAINS DD FORM 250" on the package.

(End of clause)

SECTION F OF NNG05EA01C
DELIVERIES OR PERFORMANCE

F. 1 SECTION F CLAUSES INCORPORATED BY REFERENCE

(52.247-34) F.O.B. DESTINATION (NOV 1991)
(52.242-15) STOP-WORK ORDER (AUG 1989)--ALTERNATE I (APR 1984)

(End of clause)

F. 2 PLACE OF PERFORMANCE

The effort specified by this contact shall be performed at the following location(s):

Lockheed Martin Space Systems Company
12557 Wadsworth Blvd.
Denver, CO 80201

Lockheed Martin Space Systems Company
7474 Greenway Center Drive
Greenbelt, MD 20770

(End of Text)

F. 3 SHIPPING INSTRUCTIONS--CENTRAL RECEIVING (GSFC 52.247-94) (JUL 1993)

Shipments of the items required under this contract shall be to:

Receiving Officer
Building 16W
Code 239
Goddard Space Flight Center
Greenbelt, Maryland 20771

Marked for:

NASA/GSFC
COTR/Code (As delegated by the Contracting Officer)
Greenbelt, MD 20771

Compliance with this clause is necessary to assure verification of delivery and acceptance and prompt payment.

(End of clause)

F. 4 ADVANCE NOTICE OF SHIPMENT (1852.247-72) (OCT 1988)

Ten (10) calendar days prior to shipping items identified below, the Contractor shall furnish the anticipated shipment date, bill of lading number (if applicable), and carrier identity to the Contracting Officer's Technical Representative.

(End of clause)

SECTION G OF NNG05EA01C
CONTRACT ADMINISTRATION DATA

G. 1 SECTION G CLAUSES INCORPORATED BY REFERENCE

(1852.208-81)	RESTRICTIONS ON PRINTING AND DUPLICATING (OCT 2001)
(1852.227-70)	NEW TECHNOLOGY (MAY 2002)
(1852.227-86)	COMMERCIAL COMPUTER SOFTWARE--LICENSING (DECEMBER 1987)
(1852.242-73)	NASA CONTRACTOR FINANCIAL MANAGEMENT REPORTING (JUL 2000)
(1852.245-70)	CONTRACTOR REQUESTS FOR GOVERNMENT- OWNED EQUIPMENT (JUL 1997)
(1852.245-71)	(INSTALLATION-ACCOUNTABLE GOVERNMENT PROPERTY JUN (1998)
(1852.245-73)	FINANCIAL REPORTING OF NASA PROPERTY IN THE CUSTODY OF CONTRACTORS (OCT 2003)

(End of By Reference Section)

G. 2 FINANCIAL MANAGEMENT REPORTING (GSFC 52.242-90)(FEB 2004)

(a) Requirements. This clause provides the supplemental instructions referred to in NASA FAR Supplement (NFS) clause 1852.242-73. The NFS clause and NASA Procedural Requirements (NPR) 9501.2D, "NASA Contractor Financial Management Reporting", establish report due dates and other financial management reporting requirements. NPR 9501.2D permits withholding of payment for noncompliance.

(b) Supplemental instructions. (1) Monthly (NF 533M) reports are required. Quarterly (NF 533Q) reports are also required. The reporting structure shall be in accordance with Attachment F and Attachment G entitled "Work Breakdown Structure" and "Financial Reporting Requirements", respectively, of Section J of this contract.

(2) As stated in NPR 9501.2D, NASA strongly encourages electronic contractor cost reporting. The preferred formats are Excel and Adobe. Contact the Contracting Officer for any E-Mail addresses that are not provided or which become noncurrent.

Distribution shall be as follows:

Contracting Officer, Code 210.S
E-Mail: Carlos.R.McKenzie@nasa.gov

Contracting Officer's Technical Representative,
E-Mail: Sheila.M.Stanford@nasa.gov

Resources Analyst, Code 445
E-mail: Ronnice.N.Sturdivant@nasa.gov
E-mail: Sherri.R.Hall@nasa.gov

E-mail: Richard.C.King@nasa.gov

Regional Finance Office Cost Team, Code 155
E-Mail: rfocateam@listserv.gsfc.nasa.gov

Administrative Contracting Officer (if delegated)

(c) Web sites. (1) NPR 9501.2D, "NASA Contractor Financial Management Reporting":

http://nodis3.gsfc.nasa.gov/library/displayDir.cfm?Internal_ID=N_PG_9501_002D_&page_name=main

(2) NF 533 Tutorial: (for training purposes only)

http://genesis.gsfc.nasa.gov/nf533.htm

(End of clause)

G. 3 REPAIR OR REPLACEMENT OF GOVERNMENT PR0PERTY--SPECIAL CONDITIONS (GSFC 52.245-92) (SEP 1998)

(a) Government property categorized as facilities (defined at FAR 45.301 and NASA FAR Supplement 1845.301) has been provided for the performance of this contract.

(b) Except as specified in paragraph (e) below, the Government will not authorize the replacement of any defective Government property as a direct reimbursable cost under this contract. Replacement shall be at no cost to the Government except as may be permitted by FAR 31.205-11, "Depreciation." However, the Government may authorize and reimburse the repair of defective Government property as stated in paragraph (c). If repair is not approved by the Contracting Officer, the Contractor agrees to replace any defective Government property with property owned or leased by the Contractor. However, such Contractor property need not be identical to the replaced property. Further, replacement may be waived by the Contracting Officer provided the Contractor submits a written request and demonstrates to the satisfaction of the Contracting Officer that the capability to perform the contract in an acceptable and efficient manner is not degraded.

(c) The Government may reimburse the reasonable direct cost for the repair of any Government property for which repair is determined to be an acceptable alternative. In accordance with FAR clause 52.245-5, the Contractor is required to have an approved maintenance/repair program for Government Property. The criteria in this program shall be used to determine when the contractor is required to request approval from the Contracting Officer for repair or replacement of Government property. However, in the absence of a Government approved maintenance/repair program, the Contractor must submit each repair request to the Contracting Officer. When the maintenance program requires the Contractor to inform the Contracting Officer of the need for a repair/replacement decision, the Contractor shall notify the Contracting Officer, in writing, and provide a "not to exceed" dollar amount for the repair of the property and a rationale as to why repair is the best alternative considering the age of the property, the nature of the defect(s), and the criticality of the property to the accomplishment of the requirements of the contract. If the Contracting Officer agrees that the property is still needed for contract performance and that repair is an acceptable alternative, the Contracting Officer may authorize the repair. If the Contracting Officer considers that repair is not an acceptable alternative, the Contracting Officer shall notify the Contractor and the replacement equipment or needed equivalent capability shall be provided by the Contractor in accordance with paragraph (b) above. This decision by the Contracting Officer shall not be subject to the Disputes clause of this contract.

(d) In the event that the Contractor is not selected in a subsequent recompetition of this requirement and the facility items replaced as contractor property are not needed for any other purpose, the Contractor is encouraged to offer to sell to the successor contractor any facility items that the successor contractor chooses to buy, at a fair and reasonable price.

(e) This clause shall not apply to the following items: None

(End of clause)

G. 4 CONTRACTOR ACQUIRED PROPERTY--NASA CONDITIONS (GSFC 52.245-97) (SEP 1998)

NASA FAR Supplement 1845.502-70 establishes general and specific conditions that apply to this contract for various categories of contractor acquired property.

(End of clause)

G. 5 AWARD FEE FOR END ITEM CONTRACTS (1852.216-77) (JUNE 2000)

(a) The contractor can earn award fee, or base fee, if any, from a minimum of zero dollars to the maximum stated in NASA FAR Supplement clause 1852.216-85, "Estimated Cost and Award Fee" in this contract. All award fee evaluations, with the exception of the last evaluation, will be interim evaluations. At the last evaluation, which is final, the Contractor's performance for the entire contract will be evaluated to determine total earned award fee. No award fee or base fee will be paid to the Contractor if the final award fee evaluation is "poor/unsatisfactory."

(b) Beginning 6 months after the effective date of this contract, the Government will evaluate the Contractor's interim performance every 6 months to monitor Contractor performance prior to contract completion and to provide feedback to the Contractor. The evaluation will be performed in accordance with Deorbit Module Performance Evaluation Plan to this contract. The Contractor may submit a self-evaluation of performance for each period under consideration. These self-evaluations will be considered by the Government in its evaluation. The Government will advise the Contractor in writing of the evaluation results. The plan may be revised unilaterally by the Government prior to the beginning of any rating period to redirect emphasis.

(c) (1) Base fee, if applicable, will be paid in monthly installments based on the percent of completion of the work as determined by the Contracting Officer.

(2) Interim award fee payments will be made to the Contractor based on each interim evaluation. The amount of the interim award fee payment is limited to the lesser of the interim evaluation score or 80 percent of the fee allocated to that period less any provisional payments made during the period. All interim award fee payments will be superseded by the final award fee determination.

(3) Provisional award fee payments will be made under this contract pending each interim evaluation. If applicable, provisional award fee payments will be made to the Contractor on a not more often than monthly basis. The amount of award fee which will be provisionally paid in each evaluation period is limited to 80 percent of the prior interim evaluation score. Provisional award fee payments made each evaluation period will be superseded by the interim award fee evaluation for that period. If provisional payments made exceed the interim evaluation score, the Contractor will either credit the next payment voucher for the amount of such overpayment or refund the difference to the Government, as directed by the Contracting Officer. If the Government determines that (i) the total amount of provisional fee payments will apparently substantially exceed the anticipated final evaluation score, or (ii) the prior interim evaluation is "poor/unsatisfactory", the Contracting Officer will direct the suspension or reduction of the future payments and/or request a prompt refund of excess payments as appropriate. Written notification of the determination will be provided to the Contractor with a copy to the Deputy Chief Financial Officer (Finance).

(4) All interim (and provisional, if applicable) fee payments will be superseded by the fee determination made in the final award fee evaluation. The Government will then pay the Contractor, or the Contractor will refund to the Government the difference between the final award fee determination and the cumulative provisional fee payments. If the final award fee evaluation is "poor/unsatisfactory", any base fee paid will be refunded to the Government.

(5) Payment of base fee, if applicable, will be made based on submission of an invoice by the Contractor. Payment of award fee will be made by the Cost & Commercial Account Dept., Code 155, based on issuance of a unilateral modification by the Contracting Officer.

(d) Award fee determinations are unilateral decisions made solely at the discretion of the Government.

(End of clause)

G. 6 SUBMISSION OF VOUCHERS FOR PAYMENT (18-52.216-87)(MAR 1998)

(a)The designated billing office for cost vouchers for purposes of the Prompt Payment clause of this contract is indicated below. Public vouchers for payment of costs shall include a reference to the number of this contract.

(b)(1) If the contractor is authorized to submit interim cost vouchers directly to the NASA paying office, the original voucher and one copy should be submitted to:

Cost and Commercial Accounts Department
Code 155
Goddard Space Flight Center

Greenbelt, Maryland 20771

(2) For any period that the Defense Contract Audit Agency has authorized the Contractor to submit interim cost vouchers directly to the Government paying office, interim vouchers are not required to be sent to the Auditor, and are considered to be provisionally approved for payment subject to final audit.

(3) Copies of vouchers should be submitted as may be directed by the Contracting Officer.

(c) If the contractor is not authorized to submit interim cost vouchers directly to the paying office as described in paragraph
(b), the contractor shall prepare and submit vouchers as follows:

(1) One original and one copy Standard Form (SF)1034, SF 1035, or equivalent Contractor's attachment to the Auditor.

Defense Contract Audit Agency (DCAA)
P. O. Box 170, MS 182
Denver, CO 80201-179
303-977-3191

(2) (Reserved)

(3) The Contracting Officer may designate other recipients as required.

(d) Public vouchers for payment of fee shall be prepared similarly to the procedures in paragraphs (b) or (c) of this clause, whichever is applicable, and be forwarded to the Contracting Officer.

This is the designated billing office for fee vouchers for purposes of the Prompt Payment clause of this contract.

(e) In the event that amounts are withheld from payment in accordance with provisions of this contract, a separate voucher for the amount withheld will be required before payment for that amount may be made.

(End of clause)

G. 7 DESIGNATION OF NEW TECHNOLOGY REPRESENTATIVE AND PATENT REPRESENTATIVE (1852.227-72) (JULY 1997)

(a) For purposes of administration of the clause of this contract entitled "New Technology" or "Patent Rights -- Retention by the Contractor (Short Form)", whichever is included, the following named representatives are hereby designated by the Contracting Officer to administer such clause:

Title	Office	Address (including

	Code	zip code
New Technology	504	Goddard Space Flight Center Representative Greenbelt, MD 20771
Patent	503	Goddard Space Flight Center Representative Greenbelt, MD 20771

(b) Reports of reportable items, and disclosure of subject inventions, interim reports, final reports, utilization reports, and other reports required by the clause, as well as any correspondence with respect to such matters, should be directed to the New Technology Representative unless transmitted in response to correspondence or request from the Patent Representative. Inquiries or requests regarding disposition of rights, election of rights, or related matters should be directed to the Patent Representative. This clause shall be included in any subcontract hereunder requiring a "New Technology" clause or "Patent Rights--Retention by the Contractor (Short Form)" clause, unless otherwise authorized or directed by the Contracting Officer. The respective responsibilities and authorities of the above-named representatives are set forth in 1827.305-370 of the NASA FAR Supplement.

(End of clause)

G.8 LIST OF GOVERNMENT-FURNISHED PROPERTY (1852.245-76) (OCT 1988)

For performance of work under this contract, the Government will make available Government property identified below and in Attachment **L** of this contract on a no-charge-for-use basis. The Contractor shall use this property in the performance of this contract at either the NASA/GSFC or Contractor's facility and at other location(s) as may be approved by the Contracting Officer. Under the FAR 52.245 Government Property clause of this contract, the Contractor is accountable for the identified property.

Description	***QTY***	***Schedule***	***Reference***
Gyro Interface Unit (GIU)	3	CDR plus Three (3) months.	Requirements Document 3.3.1.6
P101 Main Mechanical Umbilical Actuator	1	CDR plus Three (3) months.	Requirements Document 3.3.1.5
HST Craig-Bampton Model	1	Contract Award plus Three (3) months.	Requirements Document 3.3.2.3
Flight Support System Berthing Pin & J101 Interface Verification Tool	1	CDR plus Three (3) months.	Requirements Document 3.3.1.2.2
HRV to HST Connector Interface Plates (Rack and Panel)	1	CDR plus Three (3) months.	Requirements Document 3.3.1.11

(End of clause)

G.9 LIST OF INSTALLATION-ACCOUNTABLE PROPERTY AND SERVICES (1852.245-77) (JUL 1997)

In accordance with the clause at 1852.245-71, Installation-Accountable Government Property, the Contractor is authorized use of the types of property and services listed below, to the extent they are available, in the performance of this contract within the physical borders of the installation which may include buildings and space owned or directly leased by NASA in close proximity to the installation, if so designated by the Contracting Officer.
(a) Office space, work area space, and utilities. Government telephones are available for official purposes only; pay telephones are available for contractor employees for unofficial calls.
(b) General- and special-purpose equipment, including office furniture.
(1) Equipment to be made available is listed is as follows.

A. Office Space for up to 3 contractor personnel.
B. Office Furniture; such as desks and file cabinets for up 3 contractor personnel.
C. The Government will not provide desktop personal computers for on-site contractor personnel.

The Government retains accountability for this property under the clause at 1852.245-71, Installation-Accountable Government Property, regardless of its authorized location.
(2) If the Contractor acquires property, title to which vests in the Government pursuant to other provisions of this contract, this property also shall become accountable to the Government upon its entry into Government records as required by the clause at 1852.245-71, Installation-Accountable Government Property.
(3) The Contractor shall not bring to the installation for use under this contract any property owned or leased by the Contractor, or other property that the Contractor is accountable for under any other Government contract, without the Contracting Officer's prior written approval.
(c) Supplies from stores stock.
(d) Publications and blank forms stocked by the installation.
(e) Safety and fire protection for Contractor personnel and facilities.
(f) Installation service facilities: None
(g) Medical treatment of a first-aid nature for Contractor personnel injuries or illnesses sustained during on-site duty.
(h) Cafeteria privileges for Contractor employees during normal operating hours.
(i) Building maintenance for facilities occupied by Contractor personnel.
(j) Moving and hauling for office moves, movement of large equipment, and delivery of supplies. Moving services shall be provided on-site, as approved by the Contracting Officer.
(k) The user responsibilities of the Contractor are defined in paragraph (a) of the clause at 1852.245-71, Installation-Accountable Government Property.

(End of clause)

G. 10 PROPERTY CLAUSE APPLICABILITY--ON-SITE AND OFF-SITE (GSFC 52.245-96)(SEP 1998)

(a) Performance of this contract requires that contractor personnel and any furnished and/or acquired government property be located at both Government controlled and managed premises (on-site) and at contractor controlled and managed premises (off-site). The requirements for control and accountability of government property differ depending upon the location of the property. The applicability of the clauses in this contract to on-site and to off-site locations is indicated below.
(b) Clauses applicable to both on-site and off-site locations.
FAR clause 52.245-5, "Government Property (Cost Reimbursement, Time-and-Material, or Labor-Hour Contracts" except that para (e) does not apply to on-site locations.
NASA FAR Supplement clause 1852.245-70, "Contractor Requests for Government-Owned Equipment".
GSFC clause 52.245-92, "Repair or Replacement of Government Property--Special Conditions", if included.
GSFC clause 52.245-97, "Contractor Acquired Property--NASA Conditions".
(c) Clauses applicable only to off-site locations.
NASA FAR Supplement clause 1852.245-73, "Financial Reporting of NASA Property in the Custody of Contractors"
NASA FAR Supplement clause 1852.245-76, "List of Government-Furnished Property", if included.
(d) Clauses applicable only to on-site locations.
NASA FAR Supplement clause 1852.245-71, "Installation-Accountable Government Property (Alternate I)".
NASA FAR Supplement clause 18-52.245-77, "List of Installation- Accountable Property and Services".
GSFC clause 52.245-93, "Contractor Acquired Government Property"

(End of clause)

SECTION H OF NNG05EA01C
SPECIAL CONTRACT REQUIREMENTS

H. 1 SECTION H CLAUSES INCORPORATED BY REFERENCE

(1852.208-81)	RESTRICTIONS ON PRINTING AND DUPLICATING (OCT 2001)
(1852.223-70)	SAFETY AND HEALTH (APR 2002)
(1852.223-75)	MAJOR BREACH OF SAFETY OR SECURITY (FEB 2002)
(1852.242-72)	OBSERVANCE OF LEGAL HOLIDAYS (AUG 1992)--ALTERNATE II (SEPT 1989)
(1852.244-70)	GEOGRAPHIC PARTICIPATION IN THE AEROSPACE PROGRAM (APRIL 1985)

(End of By Reference Section)

H. 2 HANDLING OF DATA (GSFC 52.203-90) (JAN 1995)

(a) In the performance of this contract, it is anticipated that the Contractor may have access to, be furnished, or use the following categories of data (which may be technical data, computer software, administrative, management information, or financial, including cost or pricing):

(1) Data of third parties which the Government has agreed to handle under protective arrangements; and

(2) Government data, the use and dissemination of which, the Government intends to control.

(b) In order to protect the interests of the Government and the owners, licensors and licensees of such data, the Contractor agrees, with respect to any such third party or Government data that is either marked with a restrictive legend, specifically identified in this contract, or otherwise identified in writing by the Contracting Officer as being subject to this clause, to:

(1) Use, disclose, and reproduce such data only to the extent necessary to perform the work required under this contract;

(2) Allow access to such data only to those of its employees that require access for their performance under this contract;

(3) Preclude access and disclosure of such data outside the Contractor's organization; and

(4) Return or dispose of such data, as the Contracting Officer may direct, when the data is no longer needed for contract performance.

(c) The Contractor agrees to inform and instruct its employees of its and their obligations under this clause and to appropriately bind its employees contractually to comply with the access, use, disclosure, and reproduction provisions of this clause.

(d) In the event that data includes a legend that the Contractor deems to be ambiguous or unauthorized, the Contractor may inform the Contracting Officer of such condition. Notwithstanding such a legend, as long as such legend provides an indication that a restriction on use or disclosure was intended, the Contractor shall treat such data pursuant to the requirements of this clause unless otherwise directed, in writing, by the Contracting Officer.

(e) Notwithstanding the above, the Contractor shall not be restricted in use, disclosure, and reproduction of any data that:
(1) Is, or becomes, generally available or public knowledge without breach of this clause by the Contractor;

(2) Is known to, in the possession of, or is developed by the Contractor independently of any disclosure of, or without reference to, proprietary, restricted, confidential, or otherwise protectible data under this clause;

(3) Is rightfully received by the Contractor from a third party without restriction;

(4) Or is required to be produced by the Contractor pursuant to a court order or other Government action.

If the Contractor believes that any of these events or conditions that remove restrictions on the use, disclosure, and reproduction of the data apply, the Contractor shall promptly notify the Contracting Officer of such belief prior to acting on such belief, and, in any event, shall give notice to the Contracting Officer prior to any unrestricted use, disclosure, or reproduction of such data.

(End of clause)

H. 3 LIMITED RELEASE OF CONTRACTOR CONFIDENTIAL BUSINESS INFORMATION (GSFC 52.203-91) (JUN 2002)

(a) NASA may find it necessary to release information submitted by the Contractor, either in response to this solicitation or pursuant to the provisions of this contract, to individuals not employed by NASA. Business information that would ordinarily be entitled to confidential treatment may be included in the information released to these individuals. Accordingly, by submission of this proposal, or signature on this contract or other contracts, the Contractor hereby consents to a limited release of its confidential business information (CBI).

(b) Possible circumstances where the Agency may release the Contractor's CBI include, but are not limited to, the following:

(1) To other Agency contractors and subcontractors, and their employees tasked with assisting the Agency in handling and processing information and documents in the evaluation, the award or the administration of Agency contracts, such as providing both preaward and post award audit support and specialized technical support to NASA's technical evaluation panels;

(2) To NASA contractors and subcontractors, and their employees engaged in information systems analysis, development, operation, and maintenance, including performing data processing and management functions for the Agency.

(c) Except where otherwise provided by law, NASA will permit the limited release of CBI under subparagraphs (1) or (2) only pursuant to non-disclosure agreements signed by the assisting contractor or subcontractor, and their individual employees who may require access to the CBI to perform the assisting contract).

(d) NASA's responsibilities under the Freedom of Information Act are not affected by this clause.

(e) The Contractor agrees to include this clause, including this paragraph (e), in all subcontracts at all levels awarded pursuant to this contract that require the furnishing of confidential business information by the subcontractor.

(End of clause)

H. 4 REPRESENTATIONS, CERTIFICATIONS AND OTHER STATEMENTS OF OFFEROR (GSFC 52.215-90) (NOV 1999)

In accordance with FAR 15.204-1(b), the completed and submitted "Representations, Certifications, and Other Statements of Offeror", are incorporated by reference in this resulting contract.

(End of clause)

H. 5 PROVISIONING PROCEDURES

(a) The Contracting Officer is the only individual authorized to issue Provisioned Item Orders (PIOs) ordered under this contract.

(b) Ordering

(1) Supplies or services to be furnished under Section J - Attachment A, Section 15 entitled "Common Components", of this contract shall be ordered by the issuance of PIOs. Orders many be issued under this contract for the period beginning with the effective date of this contract.

(2) It is understood and agreed that the Government does not have any obligations under the terms of this contract to issue PIOs.

(3) All PIOs hereunder are subject to the terms and conditions of this clause. The contract shall control in the event of a conflict with any order.

(4) Orders shall be effective upon receipt of the PIO by Contractor.

(5) PIOs shall, as a minimum, describe the following:

a. The supplies or services being ordered;

b. The requested delivery schedule (unpriced orders) or required delivery schedule for definitized orders; and

d. Any other specifics which are required to complete the order.

(6) The Government reserves the right to issue unpriced orders under this contract. All orders shall be subject to the "Limitation of Funds" clause of this contract. PIOs shall be issued by the Contracting Officer, on Standard Form 30, "Amendment of Solicitation/Modification of Contract."

(7) Within thirty (30) days after receipt of an unpriced PIO, the Contractor shall submit a firm proposal to definitize the order. A proposal may address more than one PIO, but each deliverable item must be priced and substantiated separately within the proposal. The parties shall make every effort to negotiate firm prices for items ordered under an unpriced PIO. If it becomes apparent that the parties cannot agree on a firm price, the Contracting Officer many issue a unilateral determination of prices subject to the "Disputes" clause of this contract. Nothing in this clause shall excuse the Contractor from performing any work under this contract.

(End of Text)

H. 6 ONSITE CONTRACTOR PERSONNEL—IDENTIFICATION, REPORTING, AND CHECKOUT PROCEDURES (GSFC 52.204-99) (AUG 2003)

(a) The Contractor shall designate a representative (point of contact) for the purposes of this clause. The Contractor shall notify the GSFC Security Division, Code 240, Attention: Locator and Information Tracking System (LISTS) Manager, and the Contracting Officer's Technical Representative (COTR) of the designated representative within 15 calendar days of award of this contract. The GSFC maintained LISTS contains work and home location and contact information for personnel that have permanent NASA/GSFC identification badges. The Contractor may contact the LISTS Manager, Tel 301-286-2306 for assistance regarding LISTS.

(b) The Contractor must apply for permanent NASA/GSFC identification badges for those employees who will be employed by the contractor onsite for at least six months. The GSFC Security Division will consider permanent identification badges for other employees of the Contractor on a case by case basis, such as employees that are not resident onsite, but must frequently visit. For each employee, the Contractor must complete and submit a GSFC Form 24-27, "LISTS Form", and a NASA Form 531, "Name Check Request". The forms are available from GSFC Stores Stock or online via NASA and GSFC systems. The GSFC Form 24-27 must be signed by the COTR or the Contracting Officer. The COTR will resolve any housing or access issues, review the forms for accuracy and completeness, and return the signed forms to the Contractor. The Contractor shall forward the form(s) to the GSFC Security Division, Code 240, for the necessary checks, issuance of identification badges, and subsequent data entry into the LISTS. Arrangements for fingerprinting employees will be handled by representatives of the GSFC Security Division's ID Section.

(c) The Contractor shall submit an annotated LISTS Report each month. The GSFC LISTS Manager will furnish a LISTS print-out to the Contractor no later than the end of each month. The Contractor shall annotate this provided report to correct and update the information as follows:

(1) Draw a line through the names of employees who are no longer employed by the contractor or that no longer work onsite under the contract, and;

(2) Make handwritten changes to any other incorrect data.

The annotated LISTS Report shall be separately submitted to the GSFC Security Division, Code 240, Attention: LISTS Manager, and to the COTR by the 10th calendar day of the month.

(d) The Contractor shall ensure that all personnel who have NASA/GSFC issued identification, keys or other property who leave its employ or that no longer work onsite, process out through the GSFC Security Division, Code 240. Employees must return all GSFC issued identification and any Government property no later than the last day of their employment. The Contractor shall establish appropriate procedures and controls to ensure this is accomplished. Failure to comply may result in the exercise of Government rights to limit and control access to Government premises, including denial of access and invalidation of NASA issued badges and identification.

(End of clause)

H. 7 GOVERNMENT PREMISES—PHYSICAL ACCESS AND COMPLIANCE WITH PROCEDURES (GSFC 52.211-95) (DEC 2003)

(a)(1) The Contractor must apply for permanent NASA/GSFC Identification Badges for those employees that will be employed by the Contractor and that will be resident for at least six months at GSFC or at locations controlled by GSFC, such as GSFC leased space. Other personnel may be issued a temporary badge. All personnel must conspicuously display the GSFC badge at, or above, the waistline. Refer to GSFC clause 52.204-99, "Onsite Contractor Personnel—Identification, Reporting, and Checkout Procedures" for permanent Identification Badge issuance procedures.

(2) Visits by foreign nationals are restricted and must be necessary for the performance of the contract and concurred with by the Contracting Officer or by the Contracting Officer's Technical Representative. Approval of such visits must be approved in advance in accordance with GMI 1680.1.

(3) Access to the GSFC may be changed or adjusted in response to threat conditions or special situations.

(b) While on Government premises, the Contractor shall comply with requirements governing the conduct of personnel and the operation of the facility. These requirements are set forth in NASA-wide or installation directives, procedures, handbooks and announcements. The following cover many of the requirements:

(1) Coordinated Harassment/Discrimination Inquiry Guidelines <http://internal.gsfc.nasa.gov/directives/security.html>
(2) GMI 1040.5, GSFC Emergency Management Program
(3) GMI 1040.6, GSFC Emergency Management Plan (Greenbelt)
(4) GMI 1152.9, Facilities Coordination Committee
(5) GHB 1600.1, Security Manual
(6) GMI 1680.1, Visits of Foreign Nationals to GSFC
(7) GMI 1700.2, GSFC Health and Safety Program
(8) GMI 6730.6, Vehicle Reserved Parking
(9) GPD 8715.1, GSFC Safety Policy

(10) GPD 8870.1, Environmental Program Management
(11) GHB 1790.1, Chemical Hygiene Plan
(12) GPG 1800.1, GSFC Smoking Guidelines
(13) GHB 1860.1, Radiation Protection--Ionizing Radiation
(14) GHB 1860.2, Radiation Safety Handbook
(15) GHB 1860.3, Radiation Safety--Laser
(16) GHB 1860.4, Radiation Safety--Ultraviolet and High Intensity Radiation
(17) GPG 2570.1, Radio Frequency Equipment Licensing
(18) GPG 8715.1, Processing of NASA Safety Reporting System (NSRS) Incident Reports

Copies of the current issuances may be obtained at <http://gdms.gsfc.nasa.gov/gdms/plsql/menu_guest> or from the Contracting Officer. The above list may be modified by the Contracting Officer to include additional issuances pertaining to the conduct of personnel and the operation of the facility.

(c) The Contractor may not use official Government mail (indicia or "eagle" mail). Contractors found in violation could be liable for a fine of $300 per piece of indicia mail used. However, the Contractor is allowed to use internal GSFC mail to the extent necessary for purposes of the contract.

(End of clause)

H. 8 SMALL BUSINESS SUBCONTRACTING PLAN AND REPORTS (GSFC 52.219-90) (OCT 1999)

a. Subcontracting Plan (Contractor)

FAR clause 52.219-9, "Small Business Subcontracting Plan" is included in this contract. The agreed to Subcontracting Plan required by the clause is included as an attachment to the contract.

b. Subcontracting Plan (Subcontractors)

In accordance with FAR clause 52.219-9, the Contractor must require that certain subcontractors adopt a plan similar to the Plan agreed to between the Contractor and the Government.

c. Reporting to Contracting Officer (SF 294--Semi-annual and Final)

The Contractor shall prepare and submit Standard Form 294
(Rev. 12-98), "Subcontracting Report for Individual Contracts" in accordance with the instructions on the back of the form.

The SF 294 must be submitted to the Contracting Officer on a semi-annual basis. This report must be received no later than April 30 and October 30 each year for the reporting periods ending March 31 and September 30, respectively. A final SF 294 must be submitted after contract completion. The final SF

294 submittal must be received no later than the due date for what would have been the next semi-annual report.

d. Reporting to NASA Headquarters (SF 295--Semi-annual)

The Contractor shall prepare and submit Standard Form 295 (Rev. 12-98), "Summary Subcontract Report" in accordance with the instructions on the back of the form and in accordance with NASA FAR Supplement clause 1852.219-75, "Small Business Subcontracting Reporting" of this contract.

The SF 295 must be submitted to "NASA, Office of Procurement, Code HS, Washington, D.C. 20546-0001" on an semi-annual basis no later than April 30 and October 30 each year for the reporting periods ending March 31 and September 30, respectively.

e. Subcontractor Reporting

FAR clause 52.219-9 and NASA FAR Supplement clause 1852.219-75 require that the Contractor ensure that SF 294 and SF 295 reports are submitted by those subcontractors that have been required to adopt a Subcontracting Plan under the terms of the clause. These subcontractor reports must be submitted as required by paragraphs (c)and (d) above. The reports may be submitted though the Contractor or submitted directly. Regardless, the Contractor is responsible for ensuring proper and timely submittal of the required reports.

(End of clause)

H. 9 SMALL DISADVANTAGED BUSINESS PARTICIPATION--CONTRACT TARGETS (GSFC 52.219-91) (AUG 2001) (for offeror fill-in)

(a) This clause does not apply to, and should not be completed by, Small Disadvantaged Business (SDB) offerors unless the SDB offeror has waived the price adjustment evaluation adjustment [see para (c.) of FAR clause 52.219-23].

(b) FAR 19.1202-4(a) requires that SDB subcontracting targets be incorporated in the contract. Targets for this contract are as follows:

(c.) FAR 19.1202-4(b) requires that SDB concerns that are specifically identified by the offeror be listed in the contract when the extent of the identification of such subcontractors was part of the SDB evaluation subfactor. SDB concerns (subcontractors) specifically identified by the offeror are as follows:

Name of Concern(s)

The contractor shall notify the Contracting Officer of any substitutions of firms that are not SDB concerns.

(d) If the prime offeror is an SDB that has waived the price evaluation adjustment, the target for the work it intends to perform as a prime contractor is as follows:

Dollars Percent of Contract Value

(End of clause)

H. 10 SAFETY AND HEALTH--ADDITIONAL REQUIREMENTS (GSFC 52.223-91) (OCT 2002)

(a) Other safety and health requirements. In addition to compliance with all Federal, state, and local laws as required by paragraph (b) of NFS clause 18-52.223-70, the Contractor shall comply with the following: **None**

(b) Reporting. The immediate notification and prompt reporting required by paragraph (d) of NFS clause 1852.223-70 shall be to the to the Goddard Space Flight Center Safety and Environmental Branch, Code 205.2, Tel 301-286-2281 and to the Contracting Officer. This should be a verbal notification and confirmed by FAX or E-Mail. This notification is also required for any unsafe or environmentally hazardous condition associated with Government-owned property that is provided or made available for the performance of the contract.

(End of clause)

H.11 APPLICABILITY OF RIGHTS IN DATA (GSFC 52.227-93) (OCT 1988)

The "Rights in Data - Special Works" clause of this contract applies to the following aspects (or items): N/A

(End of clause)

H.12 RESERVED

H.13 LAUNCH DELAYS (GSFC 52.243-91) (FEB 1991)

The delivery schedule and/or period of performance of this contract is based upon a spacecraft launch date of December 2007. In the event of a Government directed delay of the launch date, the Contracting Officer may inform the Contractor, in writing, of the revised launch date, and allow the Contractor to submit a proposal for the effect of this delay on the cost, delivery schedule, or other terms of the contract. This may result in an equitable adjustment to the estimated cost, fee(s), if any, and delivery schedule or period of performance. Failure to agree to an adjustment shall be considered as a dispute under the Disputes clause. However, nothing in this clause shall excuse the Contractor from proceeding with the contract as extended.

(End of clause)

H.14 EXPORT LICENSES (1852.225-70) (FEB 2000)

(a) The Contractor shall comply with all U.S. export control laws and regulations, including the International Traffic in Arms Regulations (ITAR), 22 CFR Parts 120 through 130, and the Export Administration Regulations (EAR), 15 CFR Parts 730 through 799, in the performance of this contract. In the absence of available license exemptions/exceptions, the Contractor shall be responsible for obtaining the appropriate licenses or other approvals, if required, for exports of hardware, technical data, and software, or for the provision of technical assistance.

(b) The Contractor shall be responsible for obtaining export licenses, if required, before utilizing foreign persons in the performance of this contract, including instances where the work is to be performed on-site at any Government installation, where the foreign person will have access to export-controlled technical data or software.

(c) The Contractor shall be responsible for all regulatory record keeping requirements associated with the use of licenses and license exemptions/exceptions.

(d) The Contractor shall be responsible for ensuring that the provisions of this clause apply to its subcontractors.

(End of clause)

H.15 TASK ORDERING PROCEDURE (1852.216-80) (OCTOBER 1996)

SECTION H OF NNG05EA01C
SPECIAL CONTRACT REQUIREMENTS

(a) Only the Contracting Officer may issue task orders to the Contractor, providing specific authorization or direction to perform work within the scope of the contract and as specified in the schedule. The Contractor may incur costs under this contract in performance of task orders and task order modifications issued in accordance with this clause. No other costs are authorized unless otherwise specified in the contract or expressly authorized by the Contracting Officer.

(b) Prior to issuing a task order, the Contracting Officer shall provide the Contractor with the following data:

(1) A functional description of the work identifying the objectives or results desired from the contemplated task order.

(2) Proposed performance standards to be used as criteria for determining whether the work requirements have been met.

(3) A request for a task plan from the Contractor to include the technical approach, period of performance, appropriate cost information, and any other information required to determine the reasonableness of the Contractor's proposal.

(c) Within 10 calendar days after receipt of the Contracting Officer's request, the Contractor shall submit a task plan conforming to the request.

(d) After review and any necessary discussions, the Contracting Officer may issue a task order to the Contractor containing, as a minimum, the following:

(1) Date of the order.

(2) Contract number and order number.

(3) Functional description of the work identifying the objectives or results desired from the task order, including special instructions or other information necessary for performance of the task.

(4) Performance standards, and where appropriate, quality assurance standards.

(5) Maximum dollar amount authorized (cost and fee or price). This includes allocation of award fee among award fee periods, if applicable.

(6) Any other resources (travel, materials, equipment, facilities, etc.) authorized.

(7) Delivery/performance schedule including start and end dates.

(8) If contract funding is by individual task order, accounting and appropriation data.

(e) The Contractor shall provide acknowledgment of receipt to the Contracting Officer within 5 calendar days after receipt of the task order.

(f) If time constraints do not permit issuance of a fully defined task order in accordance with the procedures described in paragraphs (a) through (d), a task order which includes a ceiling price may be issued.

(g) The Contracting Officer may amend tasks in the same manner in which they were issued.

(h) In the event of a conflict between the requirements of the task order and the Contractor's approved task plan, the task order shall prevail.

(End of clause)

H.16 CONTRACTOR PROPOSED INNOVATIONS/ENHANCEMENTS

The Contractor shall provide the innovations/enhancements that are described under Attachment H. These innovations/enhancements, which are over and above the requirements required by the contract terms and conditions and the HRV DM requirements, were proposed by the Contractor in the proposal submitted in response to the HRV DM Request for Proposal. The incorporation of these innovations/enhancements does not relieve the Contractor from the responsibilities of meeting all other contract terms and conditions and the HRV DM requirements. The Contractor shall perform these innovations/enhancements on all work performed, unless specifically waived by the Contracting Officer in writing.

(End of Clause)

SECTION I OF NNG05EA01C
CONTRACT CLAUSES

I. 1 CLAUSES INCORPORATED BY REFERENCE (52.252-2) (FEB 1998)

This Contract incorporates one or more clauses by reference, with the same force and effect as if they were given in full text. Upon request, the Contracting Officer will make their full text available. Also, the full text of a clause may be accessed electronically at this/these address(es):

Federal Acquisition Regulation (FAR) clauses:

http://www.arnet.gov/far/

NASA FAR Supplement (NFS) clauses:

http://www.hq.nasa.gov/office/procurement/regs/nfstoc.htm

(a) FEDERAL ACQUISITION REGULATION (48 CFR CHAPTER 1)

(52.202-1)	DEFINITIONS (DEC 2001)
(52.203-3)	GRATUITIES (APR 1984)
(52.203-5)	COVENANT AGAINST CONTINGENT FEES (APR 1984)
(52.203-6)	RESTRICTIONS ON SUBCONTRACTOR SALES TO THE GOVERNMENT (JUL 1995)
(52.203-7)	ANTI-KICKBACK PROCEDURES (JUL 1995)
(52.203-8)	CANCELLATION, RESCISSION, AND RECOVERY OF FUNDS FOR ILLEGAL OR IMPROPER ACTIVITY (JAN 1997)
(52.203-10)	PRICE OR FEE ADJUSTMENT FOR ILLEGAL OR IMPROPER ACTIVITY (JAN 1997)
(52.203-12)	LIMITATION ON PAYMENTS TO INFLUENCE CERTAIN FEDERAL TRANSACTIONS (JUNE 2003)
(52.204-4)	PRINTED OR COPIED DOUBLE-SIDED ON RECYCLED PAPER (AUG 2000)
(52.204-7)	CENTRAL CONTRACTOR REGISTRATION (OCT 2003)
(52.208-8)	REQUIRED SOURCES FOR HELIUM AND HELIUM USAGE DATA (APR 2002)
(52.209-6)	PROTECTING THE GOVERNMENT'S INTEREST WHEN SUBCONTRACTING WITH CONTRACTORS DEBARRED,SUSPENDED, OR PROPOSED FOR DEBARMENT (JUL 1995)
(52.211-5)	MATERIAL REQUIREMENTS (AUG 2000)
(52.211-15)	DEFENSE PRIORITY AND ALLOCATION REQUIREMENTS (SEPT 1990)
(52.215-2)	AUDIT AND RECORDS--NEGOTIATION (JUN 1999)
(52.215-8)	ORDER OF PRECEDENCE--UNIFORM CONTRACT FORMAT (OCT 1997)
(52.215-11)	PRICE REDUCTION FOR DEFECTIVE COST OR PRICING DATA--MODIFICATION (OCT 1997)

SECTION I OF NNG05EA01C
CONTRACT CLAUSES

(52.215-13)	SUBCONTRACTOR COST OR PRICING DATA--MODIFICATIONS (OCT 1997)
(52.215-14)	INTEGRITY OF UNIT PRICES (OCT 1997)
(52.215-15)	PENSION ADJUSTMENTS AND ASSET REVERSIONS (JAN 2004)
(52.215-18)	REVERSION OR ADJUSTMENT OF PLANS FOR POSTRETIREMENT BENEFITS (PRB) OTHER THAN PENSIONS (OCT 1997)
(52.215-19)	NOTIFICATION OF OWNERSHIP CHANGES (OCT 1997)
(52.215-21)	REQUIREMENTS FOR COST OR PRICING DATA OR INFORMATION OTHER THAN COST OR PRICING DATA--MODIFICATIONS (OCT 1997)
(52.216-7)	ALLOWABLE COST AND PAYMENT (DEC 2002)
(52.219-8)	UTILIZATION OF SMALL BUSINESS CONCERNS (OCT 2000
(52.219-9)	SMALL BUSINESS SUBCONTRACTING PLAN (JAN 2002)--ALTERNATE II (OCT 2001)
(52.219-16)	LIQUIDATED DAMAGES--SUBCONTRACTING PLAN (JAN 1999)
(52.219-23)	NOTICE OF PRICE EVALUATION ADJUSTMENT FOR SMALL DISADVANTAGED BUSINESS CONCERNS (JUNE 2003)[the factor in para (b)is 10 percent} {offeror elects to waive adjustment [ ]}
(52.219-25)	SMALL DISADVANTAGED BUSINESS PARTICIPATION PROGRAM--DISADVANTAGED STATUS AND REPORTING (OCT 1999)
(52.222-1)	NOTICE TO THE GOVERNMENT OF LABOR DISPUTES (FEB 1997)
(52.222-19)	CHILD LABOR--COOPERATION WITH AUTHORITIES AND REMEDIES (JAN 2004)
(52.222-20)	WALSH-HEALEY PUBLIC CONTRACTS ACT (DEC 1996)
(52.222-21)	PROHIBITION OF SEGREGATED FACILITIES (FEB 1999)
(52.222-26)	EQUAL OPPORTUNITY (APR 2002)
(52.222-35)	EQUAL OPPORTUNITY FOR SPECIAL DISABLED VETERANS, VETERANS OF THE VIETNAM ERA, AND OTHER DISABLED VETERANS (DEC 2001)
(52.222-36)	AFFIRMATIVE ACTION FOR WORKERS WITH DISABILITIES (JUN 1998)
(52.222-37)	EMPLOYMENT REPORTS ON SPECIAL DISABLED VETERANS, VETERANS OF THE VIETNAM ERA, AND OTHER ELIGIBLE VETERANS (DEC 2001)
(52.223-5)	POLLUTION PREVENTION AND RIGHT-TO-KNOW INFORMATION (AUG 2003)—ALTERNATE I (AUG 2003)
(52.223-6)	DRUG FREE WORK PLACE (MAY 2001)
(52.223-14)	TOXIC CHEMICAL RELEASE REPORTING (AUG 2003)
(52.225-1)	BUY AMERICAN ACT--SUPPLIES (JUNE 2003)
(52-225-8)	DUTY FREE ENTRY (FEB 2000)
(52.225-13)	RESTRICTIONS ON CERTAIN FOREIGN PURCHASES (DEC 2003)
(52.227-1)	AUTHORIZATION AND CONSENT (JUL 1995)--ALTERNATE I (APR 1984)
(52.227-2)	NOTICE AND ASSISTANCE REGARDING PATENT AND COPYRIGHT INFRINGEMENT (AUG 1996)
(52.227-11)	PATENT RIGHTS-RETENTION BY THE CONTRACTOR (SHORT FORM) (JUN 1997) as modified by NASA FAR Supplement 1852.227-11

(52.227-14)	RIGHTS IN DATA--GENERAL (JUN 1987) as modified by NASA FAR Supplement 18-52.227-14--ALTERNATE II (JUN 1987)
(52.227-14)	RIGHTS IN DATA--GENERAL (JUN 1987) as modified by NASA FAR Supplement 18-52.227-14--ALTERNATE III (JUN 1987)
(52.227-16)	ADDITIONAL DATA REQUIREMENTS (JUN 1987)
(52.227-17)	RIGHTS IN DATA--SPECIAL WORKS (JUN 1987) as modified by NASA FAR Supplement 18-52.227-17
(52.227-21)	TECHNICAL DATA DECLARATION, REVISION, AND WITHHOLDING OF PAYMENT--MAJOR SYSTEMS (JAN 1997)
(52.228-7)	INSURANCE--LIABILITY TO THIRD PERSONS (MAR 1996)
(52.230-2)	COST ACCOUNTING STANDARDS (APR 1998)
(52.230-6)	ADMINISTRATION OF COST ACCOUNTING STANDARDS (NOV 1999)
(52.232-9)	LIMITATION ON WITHHOLDING OF PAYMENTS (APR 1984)
(52.232-17)	INTEREST (JUN 1996)
(52.232-22)	LIMITATION OF FUNDS (APR 1984)
(52.232-23)	ASSIGNMENT OF CLAIMS (JAN 1986)
(52.232-25)	PROMPT PAYMENT (OCT 2003)
(52.232-34)	PAYMENT BY ELECTRONIC FUNDS TRANSFER--OTHER THAN CENTRAL CONTRACTOR REGISTRATION (MAY 1999)[para (b)(1) fill-in (hereafter: "designated office"--Cost and Commercial Accounts Department, Code 155, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, FAX 301-286-1748, no later than concurrent with the first request for payment.]
(52.233-1)	DISPUTES (JULY 2002)--ALTERNATE I (DEC 1991)
(52.233-3)	PROTEST AFTER AWARD (AUG 1996)--ALTERNATE I (JUN 1985)
(52.242-1)	NOTICE OF INTENT TO DISALLOW COSTS (APR 1984)
(52.242-3)	PENALTIES FOR UNALLOWABLE COSTS (MAY 2001)
(52.242-13)	BANKRUPTCY (JUL 1995)
(52.243-2)	CHANGES--COST-REIMBURSEMENT (AUG 1987)--ALTERNATE V (APR 1984)
(52.243-6)	CHANGE ORDER ACCOUNTING (APR 1984)
(52.244-2)	SUBCONTRACTS (AUG 1998)--ALTERNATE I (AUG 1998) {paragraph (e) is "Professional and consultant costs as defined at FAR 31.205-33" and paragraph (k) is "None"}
(52.244-5)	COMPETITION IN SUBCONTRACTING (DEC 1996)
(52.245-1)	PROPERTY RECORDS (APR 1984)
(52.245-5)	GOVERNMENT PROPERTY (COST-REIMBURSEMENT, TIME—AND--MATERIAL, OR LABOR--HOUR CONTRACTS) (MAY 2004) (DEVIATION)(PIC 99-15) (SEP 1999)--(g)(5) of the clause shall read as follows: "The contractor shall notify the contracting officer upon loss or destruction of, or damage to, Government property provided under this contract, with the exception of low value property for which loss, damage, or destruction is reported at contract termination, completion, or when needed for continued performance. The Contractor shall take all reasonable action to protect the Government property from further damage, separate the damaged and undamaged Government property,

put all the affected Government property in the best possible order, and furnish to the Contracting Officer a statement of--" The balance of (g)(5) is unchanged.

(52.245-18)	SPECIAL TEST EQUIPMENT (FEB 1993)
(52.246-24)	LIMITATION OF LIABILITY--HIGH VALUE ITEMS (FEB 1997)
(52.247-63)	PREFERENCE FOR U.S.-FLAG AIR CARRIERS (JUNE 2003)
(52.247-67)	SUBMISSION OF COMMERCIAL TRANSPORTATION BILLS TO THE GENERAL SERVICES ADMINISTRATION FOR AUDIT (JUN 1997)
(52.247-1)	COMMERCIAL BILL OF LADING NOTATIONS (APR 1984)
(52.248-1)	VALUE ENGINEERING (FEB 2000)
(52.249-6)	TERMINATION (COST-REIMBURSEMENT) (May 2004)
(52.249-14)	EXCUSABLE DELAYS (APR 1984)
(52.251-1)	GOVERNMENT SUPPLY SOURCES (APR 1984)

(b) NASA FAR SUPPLEMENT (48 CFR CHAPTER 18) PROVISIONS)

(1852.203-70)	DISPLAY OF INSPECTOR GENERAL HOTLINE POSTERS (JUNE 2001)
(1852.215-84)	OMBUDSMAN (OCT 2003) The installation Ombudsman is William F. Townsend, Goddard Space Flight Center, Mailstop 100, Greenbelt, MD 20771, Business Phone: 301 286-5066, Fax 301 286-1714, E-mail address: William.F.Townsend@nasa.gov
(1852.216-89)	ASSIGNMENT AND RELEASE FORMS (JUL 1997)
(1852.219-74)	USE OF RURAL AREA SMALL BUSINESSES (SEP 1990)
(1852.219-75)	SMALL BUSINESS SUBCONTRACTING REPORTING (MAY 1999)
(1852.219-76)	NASA 8 PERCENT GOAL (JUL 1997)
(1852.219-77)	NASA MENTOR-PR0TEGE PROGRAM (MAY 1999)
(1852.219-79)	MENTOR REQUIREMENTS AND EVALUATION (MAR 1999)
(1852.223-74)	DRUG-AND ALCOHOL-FREE WORKPLACE (MAR 1996)
(1852.228-75)	MINIMUM INSURANCE COVERAGE (OCT 1988)
(1852.235-70)	CENTER FOR AEROSPACE INFORMATION (FEB 2003)
(1852.242-75)	EARNED VALUE MEASUREMENT SYSTEM (MAR 1999)
(1852.242-78)	EMERGENCY MEDICAL SERVICES AND EVACUATION APR 2001
(1852.243-71)	SHARED SAVINGS (MAR 1997)

(End of By Reference Section)

I. 2 RIGHTS TO PROPOSAL DATA (52.227-23) (TECHNICAL) (JUN 1987)

Except for data contained on pages **NONE**, it is agreed that as a condition of award of this contract, and notwithstanding the conditions of any notice appearing thereon, the Government shall have unlimited rights (as defined in the "Rights in Data--General" clause contained in this contract) in and to the technical data contained in the proposal dated 16 July 2004, upon which this contract is based.

(End of Clause)

I. 3 AVAILABILITY OF FUNDS (52.232-18) (APR 1984)

Funds are not presently available for this contract. The Government's obligation under this contract is contingent upon the availability of appropriated funds from which payment for contract purposes can be made. No legal liability on the part of the Government for any payment may arise until funds are made available to the Contracting Officer for this contract and until the Contractor receives notice of such availability, to be confirmed in writing by the Contracting Officer.

(End of clause)

I. 4 NOTIFICATION OF CHANGES (52.243-7) (APR 1984)

(a) Definitions. "Contracting Officer," as used in this clause, does not include any representative of the Contracting Officer. "Specifically authorized representative (SAR)," as used in this clause, means any person the Contracting Officer has so designated by written notice (a copy of which shall be provided to the Contractor) which shall refer to this subparagraph and shall be issued to the designated representative before the SAR exercises such authority.

(b) Notice. The primary purpose of this clause is to obtain prompt reporting of Government conduct that the Contractor considers to constitute a change to this contract. Except for changes identified as such in writing and signed by the Contracting Officer, the Contractor shall notify the Administrative Contracting Officer in writing promptly, within five (5)calendar days from the date that the Contractor identifies any Government conduct (including actions, inactions, and written or oral communications) that the Contractor regards as a change to the contract terms and conditions. On the basis of the most accurate information available to the Contractor, the notice shall state--

(1) The date, nature, and circumstances of the conduct regarded as a change;

(2) The name, function, and activity of each Government individual and Contractor official or employee involved in or knowledgeable about such conduct;

(3) The identification of any documents and the substance of any oral communication involved in such conduct;

(4) In the instance of alleged acceleration of scheduled performance or delivery, the basis upon which it arose;

(5) The particular elements of contract performance for which the Contractor may seek an equitable adjustment under this clause, including--

(i) What contract line items have been or may be affected by the alleged change,

(ii) What labor or materials or both have been or may be added, deleted, or wasted by the alleged change;

(iii) To the extent practicable, what delay and disruption in the manner and sequence of performance and effect on continued performance have been or may be caused by the alleged change;

(iv) What adjustments to contract price, delivery schedule, and other provisions affected by the alleged change are estimated; and

(6) The Contractor's estimate of the time by which the Government must respond to the Contractor's notice to minimize cost, delay or disruption of performance.

(c) Continued performance. Following submission of the notice required by (b) above, the Contractor shall diligently continue performance of this contract to the maximum extent possible in accordance with its terms and conditions as construed by the Contractor, unless the notice reports a direction of the Contracting Officer or a communication from a SAR of the Contracting Officer, in either of which events the Contractor shall continue performance; provided, however, that if the Contractor regards the direction or communication as a change as described in (b) above, notice shall be given in the manner provided. All directions, communications, interpretations, orders and similar actions of the SAR shall be reduced to writing promptly and copies furnished to the Contractor and to the Contracting Officer. The Contracting Officer shall promptly countermand any action which exceeds the authority of the SAR.

(d) Government response. The Contracting Officer shall promptly, within fifteen (15) calendar days after receipt of notice, respond to the notice in writing. In responding, the Contracting Officer shall either--

(1) Confirm that the conduct of which the Contractor gave notice constitutes a change and when necessary direct the mode of further performance;

(2) Countermand any communication regarded as a change;

(3) Deny that the conduct of which the Contractor gave notice constitutes a change and when necessary direct the mode of further performance; or

(4) In the event the Contractor's notice information is inadequate to make a decision under (1), (2), or (3) above, advise the Contractor what additional information is required, and establish the date by which it should be furnished and the date thereafter by which the Government will respond.

(e) Equitable adjustments. (1) If the Contracting Officer confirms that Government conduct effected a change as alleged by the Contractor, and the conduct causes an increase or decrease in the Contractor's cost of, or the time required for, performance of any part of the work under this contract, whether changed or not changed by such conduct, an equitable adjustment shall be made--

(i) In the contract price or delivery schedule or both; and

(ii) In such other provisions of the contract as may be affected.

(2) The contract shall be modified in writing accordingly. In the case of drawings, designs or specifications which are defective and for which the Government is responsible, the equitable adjustment shall include the cost and time extension for delay reasonably incurred by the Contractor in attempting to comply with the defective drawings, designs or specifications before the Contractor identified, or reasonably should have identified, such defect. When the cost of property made obsolete or excess as a result of a change confirmed by the Contracting Officer under this clause is included in the equitable adjustment, the Contracting Officer shall have the right to prescribe the manner of disposition of the property. The equitable adjustment shall not include increased costs or time extensions for delay resulting from the Contractor's failure to provide notice or to continue performance as provided, respectively, in (b) and (c) above.

NOTE: The phrases "contract price" and "cost" wherever they appear in the clause, may be appropriately modified to apply to cost-reimbursement or incentive contracts, or to combinations thereof.

(End of clause)

I. 5 HAZARDOUS MATERIAL IDENTIFICATION AND MATERIAL SAFETY DATA (52.223-3) (JAN 1997)--ALTERNATE I (JUL 1995)

(a) "Hazardous material," as used in this clause, includes any material defined as hazardous under the latest version of Federal Standard No. 313 (including revisions adopted during the term of the contract).

(b) The offeror must list any hazardous material, as defined by paragraph (a) of this clause, to be delivered under this contract. The hazardous material shall be properly identified and include any applicable identification number, such as National Stock Number or Special Item Number. This information shall also be included on the Material Safety Data Sheet submitted under this contract.

Material (If none, insert NONE)

....

....

....

Identification No.

....

....

....

(c) This list must be updated during performance of the contract whenever the Contractor determines that any other material to be delivered under this contract is hazardous.

(d) The apparently successful offeror agrees to submit, for each item as required prior to award, a Material Safety Data Sheet, meeting the requirements of 29 CFR 1910.1200(g) and the latest version of Federal Standard No. 313, for all hazardous material identified in paragraph (b) of this clause. Data shall be submitted in accordance with Federal Standard No. 313, whether or not the apparently successful offeror is the actual manufacturer of these items. Failure to submit the Material Safety Data Sheet prior to award may result in the apparently successful offeror being considered nonresponsible and ineligible for award.

(e) If, after award, there is a change in the composition of the item(s) or a revision to Federal Standard No. 313, which renders incomplete or inaccurate the data submitted under paragraph (d) of this clause, the Contractor shall promptly notify the Contracting Officer and resubmit the data.

(f) Neither the requirements of this clause nor any act or failure to act by the Government shall relieve the Contractor of any responsibility or liability for the safety of Government, Contractor, or subcontractor personnel or property.

(g) Nothing contained in this clause shall relieve the Contractor from complying with applicable Federal, State, and local laws, codes, ordinances, and regulations (including the obtaining of licenses and permits) in connection with hazardous material.

(h) The Government's rights in data furnished under this contract with respect to hazardous material are as follows:

(1) To use, duplicate, and disclose any data to which this clause is applicable. The purposes of this right are to--

(i) Apprise personnel of the hazards to which they may be exposed in using, handling, packaging, transporting, or disposing of hazardous materials;

(ii) Obtain medical treatment for those affected by the material; and

(iii) Have others use, duplicate, and disclose the data for the Government for these purposes.

(2) To use, duplicate, and disclose data furnished under this clause, in accordance with subparagraph (h)(1) of this clause, in precedence over any other clause of this contract providing for rights in data.

(3) The Government is not precluded from using similar or identical data acquired from other sources.

(i) Except as provided in paragraph (i)(2), the Contractor shall prepare and submit a sufficient number of Material Safety Data Sheets (MSDS's), meeting the requirements of 29 CFR 1910.1200(g) and the latest version of Federal Standard No. 313, for all hazardous material identified in paragraph (b) of this clause.

(1) For items shipped to consignees, the Contractor shall include a copy of the MSDS's with the packing list or other suitable shipping document which accompanies each shipment. Alternatively, the Contractor is permitted to transmit MSDS's to consignees in advance of receipt of shipments by consignees, if authorized by the Contracting Officer.

(2) For items shipped to consignees identified by mailing address as agency depots, distribution centers or customer supply centers, the Contractor shall provide one copy of the MSDS's in or on each shipping container. If affixed to the outside of each container, the MSDS must be placed in a weather resistant envelope.

(End of clause)

I. 6 AUTHORIZED DEVIATIONS IN CLAUSES (52.252-6) (APR 1984)

(a) The use in this solicitation or contract of any Federal Acquisition Regulation (48 CFR Chapter 1) clause with an authorized deviation is indicated by the addition of "(DEVIATION)" after the date of the clause.

(b) The use in this solicitation or contract of any NASA FAR Supplement Regulation (48 CFR Chapter 18) clause with an authorized deviation is indicated by the addition of "(DEVIATION)" after the name of the regulation.

(End of Clause)

I. 7 SUBCONTRACTS FOR COMMERCIAL ITEMS (52.244-6)(APR 2003)

(a) Definitions. As used in this clause--
"Commercial item," has the meaning contained in the clause at 52.202-1, Definitions.

"Subcontract," includes a transfer of commercial items between divisions, subsidiaries, or affiliates of the Contractor or subcontractor at any tier.

(b) To the maximum extent practicable, the Contractor shall incorporate, and require its subcontractors at all tiers to incorporate, commercial items or nondevelopmental items as components of items to be supplied under this contract.

(c)(1) The following clauses shall be flowed down to subcontracts for commercial items:

(i) 52.219-8, Utilization of Small Business Concerns (OCT 2000) (15 U.S.C. 637(d)(2) and (3)), in all subcontracts that offer further subcontracting opportunities. If the subcontractor (except contracts to small business concerns) exceeds $500,000 ($1,000,000 for construction of any public facility), the subcontractor must include 52.219-8 in lower tier subcontracts that offer subcontracting opportunities.

(ii) 52.222-26, Equal Opportunity (APR 2002)(E.O. 11246).

(iii) 52.222-35, Equal Opportunity for Special Disabled Veterans, Veterans of the Vietnam Era, and Other Eligible Veterans (DEC 2001)(38 U.S.C. 4212(a)).

(iv) 52.222-36, Affirmative Action for Workers with Disabilities (JUN 1998)(29 U.S.C. 793).

(v) 52.247-64, Preference for Privately Owned U.S.-Flag Commercial Vessels (JUN 2000)(46 U.S.C. Appx 1241 and 10 U.S.C. 2631) (flow down required in accordance with paragraph (d) of FAR clause 52.247-64).

(2) While not required, the Contractor may flow down to subcontracts for commercial items a minimal number of additional clauses necessary to satisfy its contractual obligations.

(d) The Contractor shall include the terms of this clause, including this paragraph (d), in subcontracts awarded under this contract.

(End of clause)

I. 8 COMPUTER GENERATED FORMS (52.253-1) (JAN 1991)

(a) Any data required to be submitted on a Standard or Optional Form prescribed by the Federal Acquisition Regulation (FAR) may be submitted on a computer generated version of the form, provided there is no change to the name, content, or sequence of the data elements on the form, and provided the form carries the Standard or Optional Form number and edition date.

(b) Unless prohibited by agency regulations, any data required to be submitted on an agency unique form prescribed by an agency supplement to the FAR may be submitted on a computer generated version of the form provided there is no change to the name, content, or sequence of the data elements on the form and provided the form carries the agency form number and edition date.

(c) If the Contractor submits a computer generated version of a form that is different than the required form, then the rights and obligations of the parties will be determined based on the content of the required form.

(End of clause)

I. 9 ENGINEERING CHANGE PROPOSALS (1852.243-70) (OCT 2001)--ALTERNATE II (SEP 1990)

(a) Definitions.

"ECP" means an Engineering Change Proposal (ECP) which is a proposed engineering change and the documentation by which the change is described, justified, and submitted to the procuring activity for approval or disapproval.

(b) Either party to the contract may originate ECPs. Implementation of an approved ECP may occur by either a supplemental agreement or, if appropriate, as a written change order to the contract.

(c) Any ECP submitted to the Contracting Officer shall include a "not-to-exceed" estimated cost]increase or decrease adjustment amount, if any, and the required time of delivery adjustment, if any, acceptable to the originator of the ECP. If the change is originated within the Government, the Contracting Officer shall obtain a written agreement with the Contractor regarding the "not-to-exceed" estimated cost and delivery adjustments, if any, prior to issuing an order for implementation of the change. An ECP accepted in accordance with the Changes clause of this contract shall not be considered an authorization to the Contractor to exceed the estimated cost in the contract Schedule, unless the estimated cost is increased by the change order or other contract modification.

(d) After submission of a Contractor initiated ECP, the Contracting Officer may require the Contractor to submit the following information:

(1) Cost or pricing data in accordance with FAR 15.403-5 if the proposed change meets the criteria for its submission under FAR 15.403-4; or

(2) Information other than cost or pricing data adequate for Contracting Officer determination of price reasonableness or cost realism. The Contracting Officer reserves the right to request additional information if that provided by the Contractor is considered inadequate for that purpose. If the Contractor claims applicability of one of the exceptions to submission of cost or pricing data, it shall cite the exception and provide rationale for its applicability.

(e) If the ECP is initiated by NASA, the Contracting Officer shall specify the cost information requirements, if any.

(End of clause)

SECTION J OF NNG05EA01C
LIST OF ATTACHMENTS

J. 1 LIST OF ATTACHMENTS (GSFC 52.211-101) (OCT 1988)

The following attachments constitute part of this contract:

Attachment	Description	Date
A	HRVDM Statement of Work (SOW)	June 1, 2004
B	HRVDM Requirements Document	June 1, 2004
C	HRDVM Deliverable Items List and Schedule (DILS)	June 1, 2004
D	HRVDM Deliverable Requirements Document (DRD)	June 1, 2004
E	Mission Assurance Requirements (MAR)	June 1, 2004
F	HRVDM Work Breakdown Structure (WBS)	June 1, 2004
G	HRVDM Financial Reporting Requirements	June 1, 2004
H	RESERVED	
I	HRVDM Small Business Subcontracting Plan	July 16, 2004
J	HRVDM Safety and Health Plan	July 16, 2004
K	HRVDM Mission Assurance Plan	July 16, 2004
L	List of Government Furnished Items	July 16, 2004

(End of clause)

Statement of Work (SOW)

for the

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

Table of Contents

A.0 Contract Overview

The following overview describes the responsibilities of the De-orbit Module (DM) contractor.

A.1 De-orbit Module System

The contractor shall design and build the DM element of the HST Robotics Vehicle (HRV). The DM, when combined with the Ejection Module (EM), will rendezvous with the Hubble Space Telescope (HST) and capture and dock with HST. The combined DM/EM spacecraft along with a grapple arm and a dexterous robot is the HRV. The EM is jettisoned after HST servicing is complete. After separation of the EM from the HST/DM, the DM shall provide battery augmentation for HST, provide interfaces for gyro augmentation, and provide end-of-life controlled reentry of HST.

A.2 Ejection Module Interface Control Document

The contractor shall work with NASA to define the EM interfaces and provide the DM-to-EM Interface Control Document (ICD). NASA will comply with this ICD to design and build the EM. The EM will carry all HST replacement equipment and the robotics necessary to service HST.

A.3 De-orbit Module Ground Interface

The contractor shall provide the DM Ground Test Set (DMGTS) that will process all data types and formats that the DM will transmit and receive during all phases of the mission. The DMGTS shall provide a set of Application Program Interfaces (API) that will allow the Control Center System (CCS) to interface with it.

A.4 Systems Engineering Support

The contractor shall provide system engineer(s) resident at Goddard Space Flight Center (GSFC) from the beginning of the contract through the end of HST servicing. The contractor shall provide systems engineer(s) resident at GSFC for the de-orbit mission. The engineer(s) will function as part of the HST team during Hubble Robotic Vehicle (HRV) development and provide for smooth interface coordination between all elements of the mission through servicing of HST and for de-orbit of HST.

A.5 Common Components

At the request of the Contracting Officer, the contractor or a subcontractor shall provide flight qualified additional common DM components for use in the EM. This common hardware will be purchased through the Provisioned Hardware Clause.

A.6 Ground Support Equipment

The contractor shall provide all handling fixtures, mechanical Ground Support Equipment (GSE), Electrical GSE, and test software to NASA.

A.7 Post Delivery Support

The contractor shall provide support through the HST de-orbit phase.

B.0 Introduction

The Hubble Space Telescope (HST) Program is planning the HST Robotic Servicing and De-orbit Mission (HRSDM) to perform selected functions originally planned for Space Shuttle Orbiter-based servicing during Servicing Mission 4, and to provide a safe and controlled reentry (de-orbit) capability for HST at the end of its mission. The planned launch date for the HRSDM is December 2007. This Statement of Work is for one element of the system required to perform the HRSDM, the De-orbit Module (DM). The total of all the flight elements necessary to support the HRSDM is referred to as the Hubble Robotic Vehicle (HRV). The HRV consist of four elements. The De-orbit Module, the Ejection Module, the Grapple Arm, and the Dexterous Robot. Figure 1 shows a concept design of the HRV.

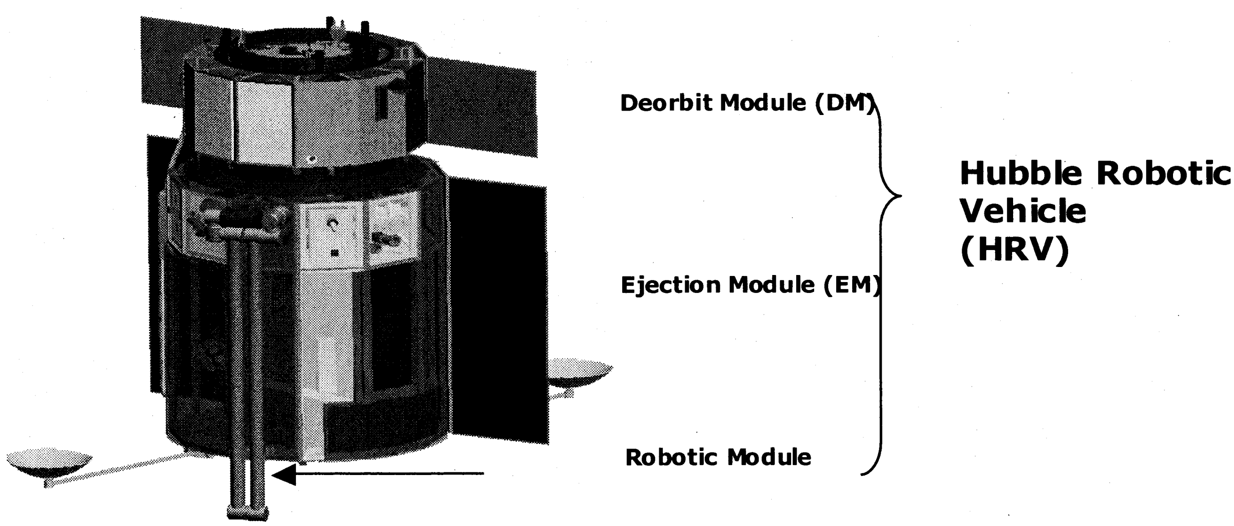


Figure 1. A concept design of the HRV.

A level 1 requirement for HST servicing missions is to ensure that the mission will "do no harm" to the HST during or after completion of the servicing activities. For HRSDM, this principle shall be adhered to by all servicing mission elements with the following exception: providing a safe and controlled de-orbit capability for HST at the end of the useful scientific life is the highest priority goal of HRSDM. Attaching the de-orbit capability to HST may have some impact on performance, but all effort shall be taken during hardware development and operations planning to ensure that the de-orbit capability does not substantially affect nominal HST operations.

Except as otherwise specified herein, the DM contractor shall be responsible for providing the DM element for HRSDM, including all DM-associated: systems engineering; integration and test (I&T); operations development support; launch site support; mission operations support through on-orbit checkout and during de-orbit; and on-orbit anomaly resolution, software maintenance, and sustaining engineering.

Additional sections of this SOW will describe mission-level system engineering and I&T that the DM contractor shall provide so that the integrated HRV and the post-HRSDM HST can take full advantage of DM capabilities.

After servicing, the contractor shall document DM mission performance through servicing. After de-orbit, the contractor shall document DM de-orbit performance.

The technical requirements for the De-orbit Module are documented in the **Requirements Document**. In the event of ambiguous or conflicting direction between the technical description given in this Section (A) and the Requirements Document, the Requirements Document shall take precedence.

B.1 Definitions

Flight Segment. The flight segment shall contain all the components of the HRV.

Ground Segment. The ground segment shall contain all the components on the ground that are required to support the HRSDM mission, including the Integration & Test equipment. This includes both HRV-specific elements as well as the HST observatory operations support infrastructure.

HST (as a segment). The flight segment of HST is the component to which the DM must interface "as-is". All requirements on HST as a segment shall refer to operationally commandable aspects (HST state/configuration). Contingencies shall be evaluated during DM design for cases where the commanded configuration is not what is intended.

HST Program. The organization that manages the day-to-day activities of HST. The HST Program is located at the NASA Goddard Space Flight Center (GSFC).

Requirements Documentation Tree Levels.

Level 1 – NASA Headquarters top-level requirements levied on the HST Program.

Level 2 – HST Program-generated and derived requirements levied on HRSDM as a whole and individually on the HRV segments and elements.

Level 3 – Derived requirements for the HRV segments and elements that are levied on deliverables within the segment or element. The contractor shall develop requirements that span segments or elements in consultation with other involved parties and through trade studies. Contractor developed requirements that span segments or elements shall be approved by the government, and documented.

Hubble Robotic Vehicle (HRV) Team. The team within the HST Program that leads the development of the HRV segment.

HRSDM or Mission. The on-orbit servicing activities intended to be performed by the HRV.

B.2 System Constituents and Mission Phases

The HRSDM development consists of the following major elements.

1. The De-orbit Module (DM).
2. The Ejection Module (EM).
3. The Grapple Arm
4. The Dexterous Robot.
5. The Ground Segment.

NASA GSFC will lead elements 2 through 5 and be responsible for the overall mission integration, test, and operations. This SOW applies to Element 1. The relationship between these elements and the existing HST elements is illustrated in Figure 2. These elements are described in more detail below.

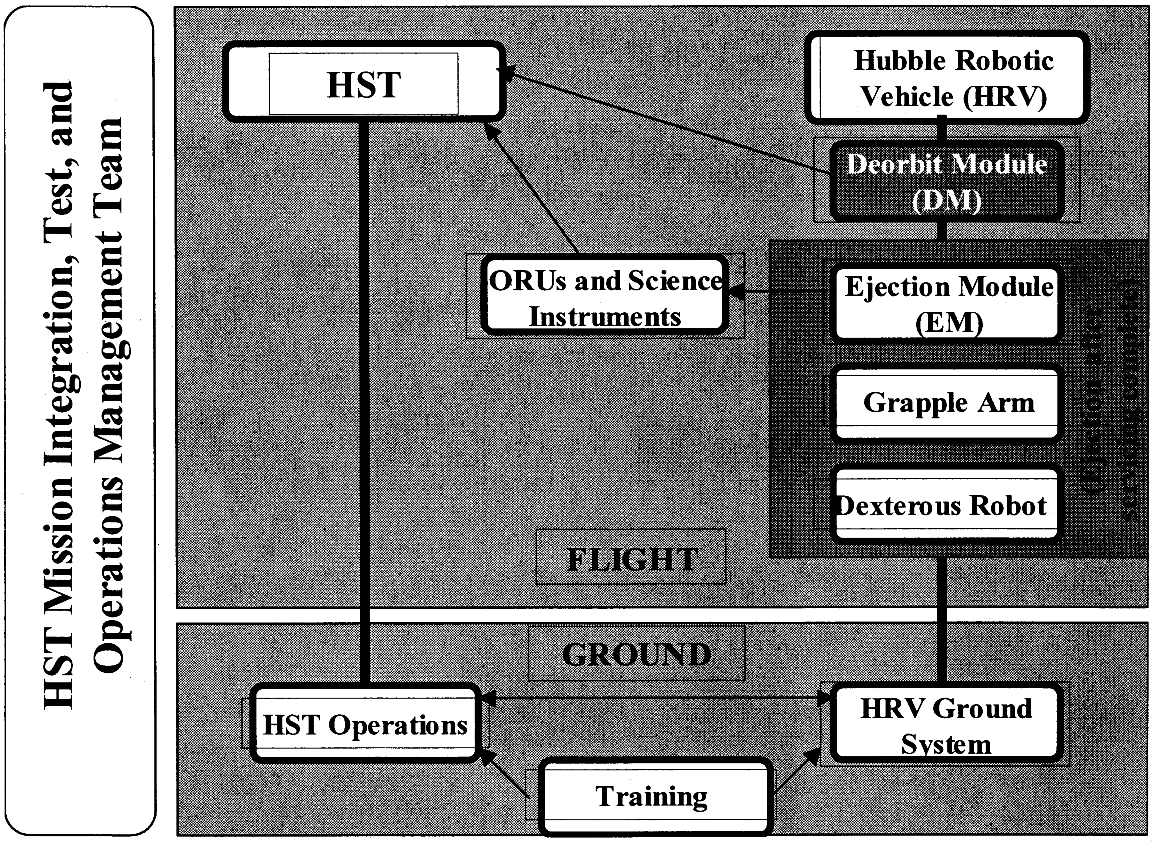


Figure 2: HRSDM robotic servicing primary constituents.

The mission phases following successful delivery of the DM flight hardware is as follows: HRV Integration and Test at GFSC, Integration and Test at the Launch Site, Launch, Orbit Insertion, Pursuit, Proximity Operations, Capture (includes docking), HST Servicing, EM Ejection, resumption of HST Science Operations (post-servicing), and safe disposal of HST at end-of-life.

B.2.1 The De-orbit Module (DM)

The DM is the element that provides the de-orbit capability for HST at the end of the HST mission. It also provides accommodation for HST augmentation subsystems that need to remain with the HST upon completion of servicing. The DM shall provide command and control functions for orbit and attitude control for the combined HRV from launch through EM ejection. The DM is the only element of the HRV that is intended to remain with the HST after servicing, with the exception of items that are installed on the HST during servicing. It has interfaces to the HST and the Ejection Module (EM), defined in the next section. The HRV (and thus DM) shall be launched using an ELV.

The DM shall include the mechanical and thermal subsystems; propulsion subsystem; guidance, navigation, and control (GN&C) subsystem; command and data handling subsystem (C&DH); electrical power subsystem (EPS); communications subsystem;

flight software; support avionics; and a direct docking (latching) subsystem to support attachment to HST for de-orbit. The DM shall be capable of initiating a controlled re-entry for the combined HST/DM vehicle at the end of the HST science mission.

The DM shall support orbit and attitude control from launch through EM ejection, using actuators located in the EM. These actuators may include momentum wheels, magnetic torquers, and thrusters. The rationale is that this additional mass should not remain attached to the HST after performing their function.

The DM shall support automated rendezvous by providing the required sensor suite as well as the necessary command and control functions. The preferred method for docking shall be accomplished while in close proximity to the HST with the assistance of the grapple arm, which mechanically and electrically interfaces to the EM.

All DM functions shall assume that the HST is in a non-responsive mode, with body rates up to those specified in the **Requirements Document**. This requires that the DM shall function as an autonomous spacecraft for all normal system functions (EPS, thermal, C&DH, GN&C, communication). The DM shall present a passive mass to the HST after servicing is completed.

The DM shall provide electrical interfaces with HST to support battery augmentation and gyro augmentation. The DM shall provide the HST augmentation battery subsystem. The DM shall house Gyro Input/Output (I/O) Electronics boxes that control the new Rate Gyro Assemblies (RGA's) that will be installed into HST for gyro augmentation as a part of the WFC3 instrument. The Gyro I/O electronics shall be supplied to the DM contractor as Government Furnished Equipment (GFE).

The DM shall support separation and ejection of the EM after completion of servicing operations.

B.2.2 The Ejection Module (EM)

The EM is an element being built in-house at GSFC. It provides storage for all the hardware that is to be robotically replaced on HST, the grapple arm and its interfaces, the dexterous robot, and stowage for the replaced science instruments during HRSDM. The EM carries the high-gain antennas for high-data-rate communication via TDRSS. At the completion of servicing, the EM shall be separated and ejected from the DM to minimize the mass attached to HST. The EM will then perform a controlled de-orbit.

B.2.3 The Grapple Arm (GA)

The grapple arm is a multi-segmented arm used to capture one of the grapple fixtures on HST during the capture phase. After the vehicles are berthed the GA is used to maneuver the dexterous robot to the appropriate worksites. The power systems and control electronics for the GA are located in the EM.

During the pursuit, proximity operations, capture, and servicing phases, the DM shall communicate with the grapple arm (via the EM) to ensure coordinated actions.

B.2.4 The Dexterous Robot (DR)

The Dexterous Robot (DR) is a two-armed, multi-degree of freedom robot used for servicing tasks. It will be stowed during the launch, pursuit, proximity operations, and capture phases. The power systems and control electronics for the DR are located in the EM.

B.2.5 The Ground Segment

The HST Program will define and conduct top-level systems analyses and trade studies pertaining to the Ground Segment and mission operations. The DM Contractor will support these trade studies to assess if the DM Ground Test System (DMGTS) should be built from a CCS test system or a Contractor provided base system.

The contractor shall provide the DMGTS that will process all data types and formats that the DM will transmit and receive during all phases of the mission. The DMGTS shall provide a set of Application Program Interfaces (API) that will allow the Control Center System (CCS) to interface with it.

C.0 ASSOCIATED DOCUMENTS AND APPLICABLE DOCUMENTS

The contractor shall meet all the requirements specified within the RFP documents and all referenced documents. All relevant documents not in the RFP can be found at http://hubble.gsfc.nasa.gov/robotic-servicing.html.

1.0 Project Management

The contractor shall integrate management disciplines, functions, and systems into an overall management activity to achieve cost-effective planning, organizing, controlling, and reporting of technical approaches, technical progress, schedules, resources, and time relationships. The contractor shall provide the project management for the overall technical and business planning, organization, direction, integration, control, and approval actions needed to accomplish the objectives of this contract. Computer-and-software-based tools shall be used to communicate the content and track the status of all activities for which the contractor is responsible under this contract. The contractor shall report programmatic issues as soon as they arise. The contractor shall give the

Government complete access and insight into all DM programmatic activities and meetings.

The contractor shall develop, implement and maintain a **Management Plan (DRD PM-01)** for the contract effort. The contractor shall electronically submit **Weekly Activity Reports (DRD PM-04)** summarizing staffing, schedule, progress, risk, technical issues and status and near-term milestones. The contractor shall submit and present **Monthly Status Reports (DRD PM-02)** summarizing staffing, cost, schedule, performance, risk, technical issues and status and near-term (one-month) milestones for all of the Project elements. These reports shall provide a summary of the activities for the month, highlight issues / problems / concerns, and briefly summarize plans for the following month for each of the level-two (N.N) DM Work Breakdown Structure (WBS) elements.

1.1 Resources Management

The contractor shall be responsible for providing the financial management necessary for the financial control and reporting of this contract. The contractor shall prepare and submit in hardcopy and electronically **Monthly Contractor Financial Management Reports (533M) (DRD PM-06)**, and **Quarterly Contractor Financial Management Reports (533Q) (DRD PM-07)**. The contractor shall report costs down to the level-one of the WBS (i.e., 1.0 Management, 2.0 Systems Engineering, 3.0 Electrical System, etc.)

The contractor shall implement an Earned Value Management System (EVMS). The system shall be keyed to the WBS. The EVMS shall enable the contractor to track cost and schedule performance and to relate technical progress and variances from the planned cost and schedule. The EVMS shall provide timely and traceable incorporation of contract changes and document their effects on the performance measurement baseline. The EVMS shall provide a basis for forecasting near-term and long-term performance. The contractor's EVMS shall be described in an **Earned Value Management System Implementation Procedures (DRD PM-08)**, and the contractor shall prepare and submit in hardcopy and electronically **Monthly Earned Value Management System Cost Performance Reports (DRD PM-09)** in accordance with NPD 9501.3A. The contractor shall also prepare and submit in hardcopy and electronically an **Integrated Baseline Review (IBR) (DRD PM-10).**

1.2 Schedule Management

The contractor shall develop, maintain and analyze start-to-finish program schedules to manage the design, development and production of the DM. The contractor shall implement an effective update process on a regular basis to ensure that resources are being used effectively. The contractor shall report schedule issues as soon as they arise. The contractor shall give the government complete access and insight into all DM schedule activities and meetings.

The contractor shall monitor its schedule performance and the status of potential and/or actual project changes; analyze the effect of schedule changes; and identify corrective actions and/or work-around plans to meet contract requirements. Changes that affect the schedules of other subsystems, external systems, milestones, or the scheduled system critical path shall be subject to prior approval of the COTR. Schedule changes not affecting the schedules of external systems or the critical path do not require COTR approval.

System and subsystem schedules shall include dependencies between the DM subsystems. The schedules shall be linked such that a slip in a deliverable on the provider's schedule shall be noted on the schedule of the receiving organization. Similarly, system and subsystem schedules shall include dependencies between the DM subsystems and other HRV external systems or subsystems. The dependencies shall be linked such that a slip in a deliverable on the provider's schedule shall be reflected.

The contractor shall describe the development, maintenance and access to its schedules in its **Management Plan (DRD PM-01)**. The contractor shall develop and maintain a current version of its schedule and include it in its **Monthly Status Reports (DRD PM-02)**. Contract deliverables for schedule are described in **Project Schedules (DRD PM-100)**.

The contractor shall allow up to monthly schedule auditing by the Government to ensure a systematic and effective schedule update process.

1.3 Configuration Management

The contractor shall define, implement, and maintain a Level 3 Configuration Management (CM) Program consistent with the **HST Program Office Configuration Management Procedure (SCM1020B)**. The contractor shall prepare, submit, and maintain an approved **Configuration Management Plan (DRD PM-33)** describing the requirements, approaches, and procedures for implementing its CM Program. This plan shall document the contractor's approach to specifying, documenting, controlling, and maintaining visibility and accountability of all aspects of the contractor's activity. Upon obtaining the HST Program's approval, the contractor's CM Plan shall be in force throughout the life of this contract. As part of its monthly progress report, the Contractor shall submit CM status.

1.3.1 Document Management

The contractor shall deliver in electronic format all required data, reports, presentation materials and documentation to all identified HST Program elements, contractor elements, and other HST Program partners. Document production and issuance shall include original preparation as well as subsequent revision and maintenance through contract completion.

Prior to the end of the contract period, the contractor shall deliver to the Government all contractor-utilized and contract-required documentation (including all engineering drawings) developed by the contractor and its subcontractors under this contract. The contractor shall include all documentation required to support nominal and off-nominal post-servicing operations of the HST. The contractor shall document the process and schedule for delivering the documentation in **Configuration Management Plan (DRD PM-33)**.

1.3.2 Photographic and Video Documentation

The contractor shall make a photographic record of the DM development and integration from the time of the first major subsystem Preliminary Design Review forward. The format for photographic documentation shall be as specified in the **Data Requirements Document**. A video record of the DM shall be created to supplement photographic documentation, especially during critical phases of hardware development and integration. This video record shall be submitted as specified in the **DM Data Requirements Document**.

1.4 Project Reviews

The contractor shall conduct reviews that measure and establish compliance with cost, schedule and technical milestones, and demonstrate fulfillment of the contract requirements. In addition to internal reviews considered necessary by the contractor, several major Project-level reviews shall be conducted. The details and contents of these major reviews are defined in the **DM Data Requirements Document**.

The major DM-level reviews required of the contractor are:

a. **System Requirements Review (DRD PM-35)**
b. **Preliminary Design Review (PDR) (DRD PM-37)**
c. **Critical Design Review (CDR) (DRD PM-39)**
d. **Mission Operations Review (MOR) (DRD PM-40)**
e. **Test Readiness Review (TRR) (DRD PM-41)**
f. **Operations Readiness Review (ORR) (DRD PM-42)**
g. **Pre-Shipment Review (PSR) (DRD PM-43)**

The major reviews are to be formal, electronic-media-based, technically-oriented, and conducted by the contractor for a review board composed of experts appointed by the HST Program. Each review shall have a detailed review package, including references. A preliminary version of the review package shall be provided electronically to the Government three (3) working days in advance of the review. A formal presentation shall be conducted using visuals that summarize the review package contents. Before the contractor proceeds with preparation of each review package, the contractor and the HST

Program shall mutually agree upon the review agenda and contents. All action items shall be tracked to completion and the resolution and rationale recorded as part of the closure.

Prior to the DM Preliminary Design Review (PDR), and Critical Design Review (CDR), the contractor shall conduct reviews for each DM subsystem for which it is responsible, as appropriate. The contractor shall provide the Government access to contractor subsystem reviews.

The contractor shall support the HST Program during Project-Level Review Board meetings and related reviews.

The contractor shall present the **Monthly Status Report (DRD PM-02)** at the monthly status reviews at the contractor's facility.

1.5 Travel

The contractor shall provide all necessary travel to implement the contract effectively.

1.6 Contract and Procurement Management

The contractor shall be responsible for traceability and reporting of all subcontractor cost and scheduling data within the associated WBS elements to the level shown in the WBS (Appendix B). The control of these data and reporting for WBS elements subcontracted by the contractor shall remain the responsibility of the contractor.

The contractor shall ensure that all of the work performed under this contract is compliant with current United States export control laws and regulations.

1.7 Risk Management

The contractor shall provide the risk management necessary to meet the requirements and schedule of this contract within budget. The contractor shall implement strategies to mitigate risks, and measure the effectiveness of the implemented strategies. The contractor shall prepare and submit a **Risk Management Plan (DRD PM-47)**.

The contractor shall define and implement the spares program necessary to minimize schedule impact for the project created by failures, contamination, or by other plausible events or conditions. In defining the spares program, the contractor shall consider the reliability, handling, and environment of subsystems, components, and parts, and hence the likelihood that these items may need to be replaced. The spares, in quantities to be defined by the contractor, shall be qualified, tested, and calibrated as appropriate.

1.8 Special Studies

The contractor shall perform special studies addressing scientific, programmatic and engineering topics related to the DM architecture, design, manufacture, integration and test, launch, and/or operations, as authorized by terms and conditions of the contract.

2.0 Systems Engineering

The contractor shall provide the personnel, equipment, and facilities necessary for all required system engineering activities, including all aspects of DM performance, testing, and evaluation. These activities include definition and allocation of system and subsystem requirements, test and calibration, and preparation of analyses, plans, reviews and procedures.

The system engineering effort shall address all considerations necessary for the development of a DM that complies with the requirements described in Section C.0 above, including electrical, structural, mechanical, thermal, calibration, and data subsystems, as well as interfaces within the DM and between the DM and HST and between DM and EM.

The English measurement units shall be the project standard and shall be used throughout the project. Engineering and manufacturing drawings using both English units and International System of Units (SI units) units are acceptable for manufacturing purposes. All units shall be clearly marked in all documentation.

The systems engineering effort includes understanding the customer's requirements, developing the operations concept, defining the DM system architecture, identifying, managing, validating, and verifying requirements, defining and managing interfaces, assessing environments, and maintaining technical budgets and margins.

2.1 Systems Engineering Management

The contractor shall define, implement and maintain a **Systems Engineering Plan (DRD SE-01)**. **DRD SE-01** shall document the contractor's approach to performing DM systems engineering and demonstrate a thorough understanding of project goals and objectives, technical issues and requirements. The contractor shall ensure necessary interaction within and among all HST Program, contractor, and subcontractor elements. The contractor shall report systems engineering and technical issues as soon as they arise. The contractor shall give the government complete access and insight into all DM systems engineering and technical activities and meetings.

The contractor shall support the HRSDM Systems Engineering Board. This board will include representatives from all of the organizations involved in the HRSDM Project. The contractor's support shall include requirements definition and verification, and coordination of all aspects of the DM element. The Contractor's systems engineering effort shall be focused in the area of the contractor's deliverables. However, since every interface affects multiple systems, the contractor shall also support systems engineering efforts in other areas, where appropriate.

The contractor shall participate in all HRSDM working groups, Integrated Product Teams (IPTs), and project reviews.

The contractor shall prepare technical reports, responses to action items from design reviews, issue and reissue reports, and prepare and manage technical memoranda.

2.2 Systems Engineering Design

2.2.1 Understanding the Requirements

The contractor shall analyze HRSDM requirements and identify driving requirements. The contractor shall describe to the customer the impact of those requirements. The contractor shall identify changes to requirements or baseline configuration that could significantly reduce cost or risk or increase performance.

2.2.2 Operations Concept Development

The contractor shall develop a De-orbit Module operations concept that covers launch through the controlled de-orbit of HST. This concept shall address launch, pursuit, proximity operations, capture, docking, servicing, HST science, and HST disposal. The operations concept shall include nominal and contingency plans.

2.2.3 Architecture Design and Development

The contract shall develop the architecture and design for the DM. The contractor shall develop a top-level EM architecture and design in order to develop the DM/EM Interface Control Document (ICD). The contractor shall coordinate its architecture definition and design activities with other HST organizations, when appropriate. The contractor shall document key trade studies.

2.2.4 Requirements Identification and Management

The contractor shall analyze the **Requirements Document**, and other applicable documents, and derive and allocate lower-level requirements across the elements covered under this contract. This includes flow-down of system requirements into software functions and hardware implementations. The contractor shall provide the **De-orbit Module Specification (DRD DM-01)**, which documents the derived requirements.

2.2.5 Interfaces and ICDs

The contractor shall participate in developing interface specifications and documentation needed to ensure the design, development, integration, verification, and successful operation of the DM. The contractor's systems engineering activities shall include elements and interfaces completely under the contractor's control (e.g., de-orbit propulsion), and elements and interfaces not completely under the contractor's control (e.g., rendezvous attitude control, the EM, GA, DR, ground segment). Examples of required Systems Engineering efforts involving multiple HRV elements include: safe modes, DM impacts to the HST Pointing Control System (PCS), DM illumination impacts on HST during rendezvous and docking, DM impacts on HST scientific instrument noise performance, DM impacts on HST operations, stray light (glint) control, contamination control, and de-orbit operations. As part of the activity supporting the development of the final ICD, the contractor shall work with NASA to determine the final partitioning of functions between the DM and EM.

The contractor shall implement an overall interface configuration management and control program. This program shall apply to elements totally under the contractor's control, and to elements to which the contractor's deliverables interface. This shall include interfaces to all associated ground support equipment (GSE), interfaces unique to I&T, and launch site facility interfaces.

2.2.5.1 Specific DM to EM Interfaces

The DM contractor shall support the definition of the detailed interfaces between the DM and the EM. In particular, since many actuators involved in orbit and attitude control reside in the EM, the DM contractor shall play a major role in defining these interfaces that are key to DM performance prior to the start of the servicing phase of the mission.

The DM contractor shall support interface definition with the EM by participation in the definition of the **DM to HST Interface Control Document** (**DRD SE-06**) and the **DM to EM Interface Control Document** (**DRD SE-07**). The HST Program will maintain these documents at Level 2.

2.2.6 Mission Environments

The contractor shall design the DM to be compatible with the environmental requirements in the Requirements Document.

2.3 Systems Engineering Implementation

2.3.1 Validation and Verification

2.3.1.1 Validation

During the design phase, the contractor shall predict performance and perform trade studies to validate that the chosen design meets the requirements.

The contractor shall establish requirements tracing to ensure that the higher-level requirements flow to lower level requirements.

The contractor shall provide requirements tracking and verification data in AP233 format (ISO 10303).

2.3.1.2 Verification

The contractor shall ensure that all requirements are verified.

The contractor shall submit the **De-orbit Module Verification Plan (DRD DM-02)** for approval by the Government. **DRD DM-02** shall document the requirement verification plan for the DM System.

The contractor shall submit the **DM Test and Verification Reports (DRD DM-04). DRD DM-04** shall include results and analyses documenting compliance with performance requirements and error budgets.

2.3.1.2.1 Models

The contractor shall develop, maintain, control and use the **DM Math Models Data Package (DRD SE-05)** for purposes of pre-flight performance prediction, design verification of all pre-launch and post-launch activities, and post-flight assessment. This data package shall consist of files and description documents that represent the simulated, as-built and verified performance of the integrated DM. **DRD SE-05** shall also provide the necessary traceability to all lower-level math models of elements, subsystems and components.

All model documentation in **DRD SE-05** shall be delivered in both electronic and paper formats. All model data files in **DRD SE-05** shall be delivered only in electronic format.

The HST Program intends to independently verify all math models used to satisfy the verification requirements of mission-critical hardware or subsystems by analysis only (i.e., without verification tests of the hardware or subsystem). All math models shall facilitate the rapid evaluation of design changes and shall support requirement flow-down and verification. The integrated modeling capability shall be used to optimize design margins and reduce costs.

As part of the monthly technical status report (**DRD PM-02**), the contractor shall provide the status of its modeling activities. This shall include the results of trade studies, requirements analyses, design verification analyses, model verifications, and the **DM Math Models Data Package (DRD SE-05)** status.

The contractor shall deliver the object and source codes, source code listings, and design details, algorithms, processes, flow charts, formulae and related materials comprising complete integrated models and descriptions. The contractor shall deliver comparable models and documentation for all supporting lower-level elements, subsystems and components used in the system models. The contractor shall deliver comparable models and documentation for all test beds. These deliverables shall enable the HST Program to reproduce, recreate, or recompile the software and reproduce, validate and refine system analysis results.

2.3.1.2.2 Mission-Level Verification

The contractor shall support HRSDM mission-level systems analysis and requirements verification, and coordinate its systems engineering activities with those of the HST Program and the other HRSDM element providers.

2.3.2 Technical Resources Budget Tracking

The contractor shall generate electronic systems engineering databases that define DM resource (e.g., mass, power, jitter) allocations and maintain DM configuration control. The contractor shall develop and institute a contingency policy that includes a phased-release plan for these resources as the design matures and is verified.

2.3.3 Technical Risk Management

The contractor shall perform a technical risk analysis of the DM element to identify potential problems, the likelihood that, and timeframe in which the problems may occur, and the severity and cost impact of the consequences if they occur. The contractor shall define and implement a process that continually assesses the risks to the DM, determines the relative threat of risks, implements strategies to mitigate significant risks, and measures the effectiveness of these strategies.

The contractor shall develop, update and deliver the **Fault Protection Requirements Document (DRD SE-03)** and the **Fault Protection Description Document (DRD SE-04)**. **DRD SE-03** and **DRD SE-04** shall govern all reliability analyses, fault tolerance requirement assessments, failure modes and effects analyses, and supporting engineering analyses and/or assessments necessary to ensure HRSDM risk containment.

As part of its risk management activities, the contractor shall utilize formal risk management processes (e.g., failure modes and effects analysis, fault tree analysis and probabilistic risk assessments), and design-for-safety methodologies. The contractor shall perform these activities for the elements they are responsible for under this contract and support the HST Program in effecting risk management for the entire HRV, launch and ground systems, and operations activities. Analyses performed as part of Technical Risk Management shall be documented and delivered to the Government upon request.

3.0 Electrical System

The contractor shall develop the power system, command & data handling system, RF communications system, and other electrical system components, such as harness, necessary to meet the DM requirements as defined in Section C.0. Specific efforts associated with the electrical system are below.

3.1 Electronic Parts and Radiation Effects

The contractor shall plan and implement an electrical, electronic, and electromagnetical (EEE) Parts Control Program that complies with **HRSDM Project Mission Assurance Requirements (SMR-5000)**. Electronic parts selected shall be appropriate for the mission and for the expected radiation environments.

3.2 Power System

As part of the power system design, the contractor shall perform the following analyses and present the results at the CDR:

1) Energy Balance Analysis- The contractor shall perform a detailed energy balance analysis for the power system. This analysis shall include a detailed solar array model including temperature and degradation effects. This analysis shall include a detailed battery modeling. This analysis shall include a minute-by-minute loads analysis and the effect on battery and solar array loading.

2) Stability Analysis- The contractor shall perform a detailed stability analysis of the power system control. The analysis shall demonstrate that the control system has adequate phase and gain margin.

3) Battery Cell Life Analysis- The contractor shall perform a detailed battery cell life analysis to demonstrate acceptable mission life. The analysis will use

life test data as available. The analysis may include cell life testing to augment the analysis as necessary.

4) Solar Array Analysis- The contractor shall perform a shadowing/ hotspot analysis to demonstrate the adequacy of the SA design over the yearly range of sun angles and spacecraft orientations.

5) Power Bus Transient Analysis- The contractor shall perform a load fault analysis to demonstrate the adequacy of the power distribution system.

6) Power Bus Distribution Analysis- The contractor shall perform a power distribution analysis to verify adequacy of the power distribution system.

7) SA Life Test Analysis- The contractor shall perform a life test analysis for the SA design to verify that the design requirements are met over the life of the mission. It may be necessary to build and test a qualification board (q board) to demonstrate the various new manufacturing technologies involved in the design. It may be necessary to subject the q board to life cycle thermal testing and/or thermal/vacuum testing to demonstrate acceptable mission life.

If the battery uses cells greater than 40 Ah, the contractor shall, by CDR, demonstrate cell balancing circuitry and cell by-pass switches, or the contractor shall provide analysis that demonstrates that their battery does not need these devices.

3.3 Command and Data Handling

The contractor shall perform the following C&DH analysis and present the results at the PDR and CDR:

1. Computer Processor utilization analysis. At time of CDR, the contractor shall analyze and demonstrate less than or equal to 40% utilization.
2. Computer Memory utilization analysis. At time of CDR, the contractor shall analyze and demonstrate less than or equal to 50% utilization.
3. Bus Bandwidth utilization analysis. At time of CDR, the contractor shall analyze and demonstrate less than or equal to 40% utilization on all busses, both internal and external.
4. Dedicated I/O utilization analysis. Dedicated I/O is defined as all C&DH I/O that is not communicated via a standard C&DH Bus, such as High Level Discrete commands, Discrete Telemetry inputs, Analog Telemetry inputs, RS-422 interfaces, … At time of CDR, the contractor shall verify at least a 25% unutilized spare capability of each type of dedicated I/O function.
5. Non-volatile Memory Storage utilization analysis. If implemented, at time of CDR, the contractor shall analyze and demonstrate less than or equal to 50% utilization.

3.4 Communications

The contractor shall design, analyze, develop and test the DM communications subsystem compatible with the Ground Network (GN) and the Space Network (SN).

The contractor shall provide resources to support testing of the Communications Subsystem (CS) for compatibility with the GN and SN.

The contractor shall also provide the technical information necessary for the creation of an RFICD (Radio Frequency Interface Control Document) that describes all the RF interfaces between the DM and each of the following: HST, EM, the GN, and the SN.

3.5 Electrical System Accommodations

The contractor shall provide an **Electromagnetic Compatibility (EMC) Control Plan (DRD SE-02)** describing the overall approach and requirements of its electromagnetic interference (EMI)/EMC control program.

The contractor shall develop and deliver all Electrical GSE (EGSE) necessary to support HRV integration and test.

4.0 Mechanical System

The contractor shall develop the structures, mechanisms, docking structure, and Ground Support Equipment necessary to meet the DM requirements as defined in section C.0.

The contractor shall design the DM with consideration given to ease of access and integration. After integration of the DM to the HRV system, all major components of the DM, including electronics, sensors, actuators, thermal hardware (e.g., heat pipes), and propulsion lines, shall be accessible for test, repair, and removal if required, with minimal impact to the overall level of integration of the HRV. Accommodations such as GSE-hinged doors, access panels, and the like shall be considered. Alignment critical interfaces shall be pinned to allow for removal and reassembly.

The contractor shall provide detailed 3-D CAD models of the DM, including all subsystem components, in a format compatible with the HRV overall assembly model per **Math Models Data Package (DRD SE-05)**. The contractor shall provide the model in ProE or IDEAS format if available, otherwise STEP or IGES format is acceptable.

The contractor shall provide detailed structural analyses of the entire DM, including all components. The analyses shall verify the structure in sufficient detail and to ensure the capability to withstand and survive launch and ascent loads, including the Ejection Module (EM) as an attachment to the DM via an appropriate separation ring arrangement. NASA will provide a simplified EM model for this analysis. Finite Element Models, when developed, shall be delivered, along with associated documentation and correlation tests as appropriate. The effects of any thermal inputs shall be reflected in the analyses as appropriate. The structural analysis is described in **Math Models Data Package (DRD SE-05)**.

The contractor shall provide Mechanical Ground Support Equipment as developed, to support integration and testing at the GSFC. MGSE that directly interfaces with flight deliverable items shall be assembled and maintained to the same standards as the deliverable flight items, especially calibration control and configuration management. This information shall be documented. This shall include shipping containers. The contractor shall deliver procedures for the use of the MGSE. The contractor shall provide strength and stability analyses in support of safety documentation.

5.0 Thermal System

5.1 DM Thermal System Design

The contractor shall design the thermal control system (TCS) for the DM. It will design all the DM spacecraft components within the operational and survival limits to insure satisfactory operation of the DM.

5.2 DM Thermal Analyses

The contractor shall develop detailed Geometric Math Models (GMM) and Thermal Math Models (TMM) of the DM. These shall be used to perform worst case thermal analyses and verify the DM Thermal Control System (TCS) for all mission modes. In addition, thermal analysis and design shall be performed at the box and board level.

5.3 DM Thermal Interface Requirements

The DM TCS shall be thermally independent of the EM and HST interfaces.
The EM or HST spacecraft shall not be used as a heat source or sink. Worst-case conductive and radiative heat transfer between the EM spacecraft and the DM will be defined by GSFC in an Interface Control Document (ICD).

The DM contractor shall supply a Reduced Geometric Math Model (RGMM) and a Reduced Thermal Math Model (RTMM) to NASA/GSFC thermal per the requirements stated herein. GSFC shall incorporate these models into the all-up observatory models and perform thermal analyses as necessary to verify the DM design.

The contractor will define the worst-case conditions and deliver these design cases to NASA/GSFC/HRSDM thermal team to review and verify.

5.4 Design Verification

The contractor shall perform thermal vacuum and thermal balance testing to verify the TCS meets all mission requirements. As a minimum, the contractor shall define the worst hot and cold operational conditions and the worst hot and cold survival conditions for review to NASA.

5.5 Thermal deliverables

The contractor shall provide a Reduced Geometric and Thermal Math Models (RGMM and RTMM) to NASA one month prior to mission PDR, one month prior to mission CDR, and 3 months prior to the start of HRV thermal vacuum/thermal balance testing. The reduced Geometric Math Model (GMM) of the DM shall be provided to NASA in Thermal Synthesizer System (TSS) with less than 100 (TBR) external surfaces. The RTMM shall be in SINDA format with less than 200 (TBR) nodes. Thermal model requirements are described in **Math Models Data Package (DRD SE-05)**.

5.6 Thermal Model Criteria

The deliverable RGMM/RTMMs of the DM shall be correlated to the detailed thermal models within 2°C for critical node/components.

<u>Additional documentation required as deliverables:</u>

Test plans, verification matrixes, test report (correlated to between 2 and 5 degrees Celcius with test data).

5.7 DM Thermal Testing

The DM shall be fully flight qualified prior to integration with the EM .
All components shall be tested in thermal vacuum prior to DM integration in accordance with GEVS. The DM will conduct hot/cold thermal cycles at qualification levels and hot/cold and survival thermal balance (shall be performed as an assembly prior to Observatory delivery to GSFC) as per GEVS. As a minimum, the contractor shall conduct two hot starts, two cold starts, 4 hot soaks, 4 cold soaks, worst hot nominal mission case, worst cold nominal mission case, and worst cold survival case.

6.0 Guidance, Navigation, and Control

6.1 GN&C Systems Engineering

The contractor shall design the GN&C system for the DM. The GN&C system design shall be capable of meeting DM GN&C requirements during all phases of the mission. The contractor shall develop a **GN&C Planning Document (DRD GNC-01)** that shall include a navigation plan, a control plan, an autonomy plan, an abort plan as well as a description of the fault detection, isolation, and recovery approach as relevant to capture aborts.

The contractor shall develop and deliver documentation for all GN&C-related interfaces between the EM and the DM including the interface for the command, control, and monitoring of EM propulsion and actuation systems as part of the **DM/EM ICD (DRD SE-07).**

The contractor shall provide estimates of **DM Mass Properties (DRD GNC-03).**

The contractor shall provide hardware performance specifications for all DM GN&C components and all components specified by the contractor for the EM. **GN&C Hardware Specifications (DRD GNC-04)**

The contractor shall perform all analyses and GN&C systems engineering required to allocate (from system and subsystem requirements) and identify GN&C requirements in accordance with the **GN&C Requirements Specification** (GRS) **(DRD GNC-21)**. All requirements shall be forward and backward traceable between system and GN&C requirements and between software requirements, design, and test.

The Requirements phase shall be concluded when the contractor has responded to all action items from the successful SRR.

GN&C design (preliminary and detailed) shall be subject to peer review by design walk-throughs. Inclusion of all GN&C requirements shall be assured. HST Program representatives may attend these reviews at their discretion. Action items shall be tracked by the contactor through completion.

The Preliminary Design phase shall be concluded when the contractor has responded to all action items from the successful PDR. The Detailed Design phase shall be concluded when the contractor has responded to all action items from the successful CDR.

The contractor's testing approach and methodology shall be documented in the **GN&C Test Plan (DRD GNC-17)**. All phases of the GN&C testing, from informal routine and function tests through the Acceptance Tests shall be carried out conforming to the documented plan. Detailed testing procedures shall be captured and maintained in the **GN&C Test Procedures and Results (DRD GNC-18)**. Electronic versions of test results shall be accessible to the government. Final GN&C Acceptance Tests shall be documented, verified and validated through the **GN&C Acceptance Test Report (DRD GNC-19)**.

The contractor shall support their internal V&V representatives. Support shall consist of providing assistance in preparing and conducting tests, evaluating and interpreting test results, analyzing problems identified during testing, and accessing software and facilities.

6.2 Attitude Determination and Control System (ADCS)

The contractor shall design, build (or procure), and deliver all necessary component hardware to ensure that the ADCS meets all applicable requirements. The contractor shall deliver mathematical models of each component in accordance with **DRD SE-05**.

The contractor shall develop and implement the flight software for attitude determination and control. The contractor shall deliver the flight software documentation and releases per the schedule and instructions established in the Flight Software Section. The contractor shall also deliver high-level simulators of the ADCS in accordance with **Subsystem High-Level Software Simulator(s) (DRD SW-18)**.

The contractor shall deliver an error budget and performance analysis for attitude control during all phases of the mission for which DM is responsible for the attitude control per **ADCS Performance Analysis (DRD GNC-05).**

6.3 Trajectory Design

The contractor shall deliver a **Trajectory Analysis and Maneuver Planning Document (DRD GNC-06)**.

6.4 Absolute Orbit Determination

The contractor shall design, build (or procure), and deliver all necessary component hardware to ensure that absolute orbit determination meets all applicable requirements. The contractor shall deliver mathematical models of each component in accordance with **DRD SE-05**.

The contractor shall develop and implement the flight software for absolute orbit determination. The contractor shall deliver the flight software documentation and releases per the schedule and instructions established in the Flight Software Section. The contractor shall also deliver high-level simulators of the Orbit determination system in accordance with **DRD SW-18**.

The contractor shall deliver an error budget and performance analysis for orbit determination during all phases of the mission for which DM is responsible for orbit determination per **Orbit Determination Performance Analysis (DRD GNC-07).**

6.5 Propulsion

The contractor shall design, build (or procure), and deliver all necessary component hardware to ensure that the Propulsion System meets all applicable requirements. The contractor shall deliver mathematical models of each component in accordance with **DRD SE-05**.

The contractor shall develop and implement the flight software for operation of the Propulsion System. The contractor shall deliver the flight software documentation and releases per the schedule and instructions established in the Flight Software Section. The contractor shall also deliver high-level simulators of the Propulsion System in accordance with **DRD SW-18**.

The contractor shall perform a comprehensive design analysis of the propulsion system that includes, as a minimum, design trades and options, performance of the chosen design, component layout, component specification and heritage information, and propellant budget analysis per **Propulsion Design Analysis (DRD GNC-08).**

The contractor shall deliver a propulsion system fluid analysis including plume impingement effects, slosh, pressure drop and waterhammer (surge pressure) per **Propulsion Fluid Analysis (DRD GNC-09)**.

The contractor shall deliver a **Propulsion System Structural Analysis (DRD GNC-10)**.

The contractor shall deliver a **Propulsion System Thermal Analysis (DRD GNC-11)**.

6.6 Relative Navigation and Control System

The contractor shall design, build (or procure), and deliver all necessary component hardware to ensure that the Relative Navigation and Control System meets all applicable requirements. The contractor shall deliver one engineering test unit; with identical form, fit, and function to the flight unit; for each sensor. The contractor shall deliver mathematical models of each component in accordance with **DRD SE-05**.

The contractor shall develop and implement the flight software for operation of the Relative Navigation and Control System. The contractor shall deliver the flight software documentation and releases per the schedule and instructions established in the Flight Software Section. The contractor shall also deliver high-level simulators of the Relative Navigation and Control System in accordance with **DRD SW-18**.

The contractor shall deliver an error budget and performance analysis for the relative vehicle control system to be used during the pursuit, proximity operations, and capture phases per **Relative Control Performance Analysis (DRD GNC-12)**.

The contractor shall deliver an error budget and performance analysis of the relative navigation system to include Monte Carlo simulation of the relative navigate state estimation process with realistic sensor error characteristics. This analysis shall also include an assessment of the performance of the sensors in all probable lighting conditions per **Relative Navigation Performance Analysis (DRD GNC-13)**.

The contractor shall deliver analysis of the interaction between the motion of the robotic (grappling and servicing) arm and the motion of the HRV and the HRV/HST combined vehicle respectively per **Coupled Motion Analysis (DRD GNC-14)**.

The contractor shall deliver analysis of the plume impingement on HST and the effect on the HST system motion per **Plume Impingement Analysis (DRD GNC-15)**.

All software packages must accommodate all vehicle configurations (DM+EM, HST+DM+EM, DM+HST) and mission phases for which DM hosts the vehicle control software.

7.0 Flight Software

7.1 Software Definitions

7.1.1 Flight Software Element

Flight Software (FSW) for the DM/EM is embedded real-time software and includes flight firmware found in the on-board microprocessor(s) and embedded in the various spacecraft hardware subsystems. Some of the functions provided by the FSW are: real-time operating system (may be COTS), time management, guidance, navigation, and control for multiple mission phases and spacecraft configurations, Relative sensor suite processing, telemetry monitoring, command storage and metering, spacecraft internal communication bus control, failure detection and correction, bulk memory management, and ground operations interface. Flight Software also encompasses all non-deliverable, on-board microprocessor(s) software used in support of testing the Flight software Element.

The contractor shall treat the software component of firmware, which consists of computer programs and data loaded into a class of memory that cannot be dynamically modified by the computer during processing (including programmable read-only memories (PROMs), programmable logic arrays, digital signal processors, Field Programmable Gate Arrays (FPGAs), etc.) as flight software for the purposes of this SOW.

Likewise, for any autogenerated software from databases, models or other sources, these sources as well as the autogenerated code shall be considered Flight Software for the purposes of this SOW.

The contractor shall be responsible for and deliver the complete FSW image in the DM. The contractor shall deliver a FSW image for the EM, common to the DM below the application level, to which government-supplied application programs can be easily added by the government. The contractor may contribute GN&C and other applications to the EM. Data and commands passed between the DM and the EM shall be as specified in the Flight Software ICD as part of the **Software Requirements Specification (DRD SW-04)**. Based on the contractor's **DM/EM ICD (DRD SE-07)**, the contractor shall specify the portions of the EM FSW to be developed and validated by the Government. For all DM and EM FSW delivered by the contractor, the FSW DRDs shall be applicable.

7.1.2 Software Development and Validation (SDV) Software Element

Software Development and Validation software for the DM/EM supports the development and test of the Flight software. It includes host development computer operating systems, high-level language compilers and debuggers, autocode generator software systems, machine language emulators, and test scenarios and procedures. It includes the software in the HRV simulators that models the sensors, actuators, and attitude environment and dynamics. It also includes development support software such as document and code configuration management systems.

7.1.3 Software Criticality Classification

All DM/EM software within the Flight and SDV Elements shall be classified as belonging to one of the following criticality classifications and managed accordingly:

(a) "Mission critical" software is all software whose failure will cause permanent loss of the ability to successfully service and de-orbit the HST. Included in this classification shall be all DM/EM Flight software and firmware plus the ground software necessary to verify the correctness of the flight software (e.g., sensor, effector, and dynamics model software).

(b) "Mission support" software is any software whose failure can impair any part of the mission. Recovery from failure of this class of software results in recovery of the ability to service and de-orbit the HST.

(c) "Engineering analysis" software is that software used in engineering analysis and simulations on an as-needed basis.

(d) "Commercial" software includes facility computer operating systems, software packages (e.g., mathematics packages, graphics packages), and high-level-language compilers employed in developing and maintaining software components. Commercial software that is acquired for integral use within planned operational elements shall be assigned a criticality equal to that of the element of which it is a part.

7.1.4 Software Types

All DM/EM software within the Flight and SDV Elements shall be classified as belonging to one of the following types and managed accordingly:

(a) "Developed" software - This is all software developed in accordance with the full life cycle as defined in the contractor's Software Management Plan.

(b) "Reuse" software - This is any software that has been developed by previous projects which can be used in significant portions to reduce development cost or improve reliability of current projects.

(c) "Heritage" software - This is any Reuse software which has not only been previously developed, but which has been successfully flown (Flight Software Element), or successfully used for an equivalent Project (SDV Element).

(d) "Off-the-Shelf (OTS)" software - This includes any software purchased from a vendor including embedded run-time systems, data- base systems, mathematics and graphic packages, compilers, operating systems, etc.

7.1.4.1 Commercial-, Modified-, and Government-Off-the-Shelf (COTS, MOTS and GOTS) Software

Commercial-Off-the-Shelf (COTS) software - Software that is sold, leased, or licensed to the general public, either as a stand alone software product or embedded in a software system.

Modified-Off-the-Shelf (MOTS) software - COTS software that is modified to meet unique requirements of a specific customer. This software requires ongoing unique maintenance for the life of the system not normally offered by the vendor.

Government-Off-the-Shelf (GOTS) software - Software provided to the customer as GFE with no warranty or maintenance provided.

For all OTS software that is integral to Mission Critical software, the contractor's software purchase agreements with product vendors (or the Government, as applicable) shall include delivery of the OTS source code with the product and any upgrade purchased or received.

This section does not pertain to Commercial Off-the-shelf (COTS) software that is an integral part of any unmodified commercial test equipment used on the HRV program.

The contractor may choose to use OTS software to satisfy all or part of its requirements as long as the requirements below are met, and details are provided in the contractor's Software Management Plan.

7.1.4.1.1 COTS, MOTS and GOTS Trade Studies

The selection of an OTS product is both a technical and financial decision. Before trade studies are begun, all of the requirements relative to the application for which OTS products are to be considered shall be gathered and divided into categories ranging from "Must meet" to "Nice to have". For Mission Critical software, any deficiencies shall be corrected by the vendor, third party, or contractor.

Trade studies shall include, at a minimum, compatibility with other system elements, hardware and software interfaces, certification costs, cost of "wrapper" or "bridge" software, full life cycle costs, costs for special risk mitigation actions (see next section), vendor support agreements, other direct and indirect costs or benefits attributable to the use of the OTS product, and custom developed alternatives.

The government shall approve the use of an OTS product.

7.1.4.1.2 COTS, MOTS and GOTS Risk Mitigation

If an OTS product is to be used in a software system, the risk of its use shall be reflected as an element of the **Risk Management Plan (DRD PM-47).** The contractor shall mitigate this risk through actions such as escrowing the source code and extending the vendor's customary product support life-cycle.

7.2 Software Management, Requirements, Development, Verification, and Testing

The contractor shall document their software management approaches and processes for software analysis, design, development, documentation, version control, test, validation, risk management, and assurance of all software products in the **Software Management Plan** (SMP) **(DRD SW-01)** document, delivered with the proposal. The contractor shall adhere to the SMP as approved by the government.

The contractor shall delineate the plan for deliveries of software, documentation, and test facilities (see section 7.7 for the description of the three deliverable test facilities. The plan shall be documented in the **Software Delivery and Operations Transition Plan (DRD SW-02)** delivered with the contractor's proposal, and will be subject to approval by the government. Also included in this plan is a summary of the contractor's recommended procedure for the government's incorporation and validation of additional FSW application programs into the delivered EM FSW image.

7.2.1 **Planning and Requirements Life Cycle Activities**

In the **Software Development Activities Plan (DRD SW-03)**, the contractor shall describe their processes and activities used in the development and testing of the various types of software being acquired, acknowledging the fact that not all software has the same criticality level or process requirements (reference the classification requirements in sections 7.1.3 and 7.1.4.

The contractor shall perform all analyses and software systems engineering required to allocate (from system and subsystem requirements) and identify software requirements in accordance with the **Software Requirements Specification** (SRS) **(DRD SW-04)**. All requirements shall be forward and backward traceable between system and software requirements and between software requirements, design, and test.

The Requirements phase shall be concluded when the contractor has responded to all action items from the successful Software Requirements Review (SWSRR) per **Software Review Packages (DRD SW-15).**

7.2.2 Design Life Cycle Activities

The contractor's Flight Software Manager shall have delivered to him or her one or more **Algorithm Design Documents** (ADD), in accordance with **DRD SW-05**, for DM/EM subsystems contributing requirements to the Flight software. DM Subsystem managers shall be responsible for delivering accurate algorithm requirements in a timely manner such that the Flight software deliverable schedule based on these algorithms can be met.

Software design (preliminary and detailed) shall be subject to peer review by design walk-throughs. Inclusion of all software requirements shall be assured. Government representatives may attend these reviews at their discretion. The contactor shall track action items through completion.

The contractor shall deliver the **Software Design Document (DRD SW-06)**. The Preliminary Design phase shall be concluded when the contractor has responded to all action items from the successful Software Preliminary Design Review (SWPDR) per **Software Review Packages (DRD SW-15)**. The Detailed Design phase shall be concluded when the contractor has responded to all action items from the successful Software Critical Design Review (SWCDR) per **Software Review Packages (DRD SW-15)**.

The contractor shall deliver the **Software User and Maintenance Manual (DRD SW-11)**, and the **Software Development and Validation Facility User's Manual (DRD SW-13)**.

7.2.3 Implementation and Delivery Life Cycle Activities

The contractor's testing approach and methodology shall be documented in the **Software Test Plan (DRD SW-07)**. All phases of the software testing, from informal routine and function tests through the Acceptance Tests shall be carried out conforming to the documented plan. Detailed testing procedures shall be captured and maintained in the **Software Test Procedures and Results (DRD SW-08)**. Electronic versions of test results shall be accessible to the government. Formal Software Tests shall be documented, verified and validated through the **Software Test Report (DRD SW-09)**.

Each CSU shall be unit tested by its developer as part of implementation. A software test above the CSU level shall not be developed or performed by the same individual who developed the code under test.

The contractor shall subject each CSU to code reading review by cognizant developers other than the CSU author and a Software QA representative. The code reading shall verify that each CSU is in compliance with the documented and approved programming practices, conventions, and standards, as well as assuring it meets both its intended requirements and design. Government representatives may attend these reviews at their discretion. The contractor shall track action items through completion.

The contractor shall perform regression testing prior to version releases to ensure the integrity of existing software. With each delivery of verified and tested software **(Flight Software Release DRD SW-19)**, the contractor shall concurrently deliver a **Software Version Description Document** (VDD) **(DRD SW-10)**.

The purpose of the Software Test Readiness Review (SWTRR) per **Software Review Packages (DRD SW-15)** shall be to assess whether the contractor has adequately prepared for formal software acceptance testing to include, at a minimum, the check-out of test procedures, test cases, and requirements traceability. With this phase of testing, the contractor shall prepare for formal monitoring of software testing by QA, the contractor's System staff, and government personnel to include the NASA IV&V staff. Upon successful completion of this phase of testing, the contractor shall close out all action items and prepare for formal delivery of the software.

The contractor shall support their internal V&V representatives. Support shall consist of providing assistance in preparing and conducting tests, evaluating and interpreting test results, analyzing problems identified during testing, and accessing software and facilities.

The Flight Operations Team and HRSDM Project FSW Development/V&V Team (see section 7.4.2) shall be trained by the contractor in the usage of the Flight Software, the FDVF, and the HRV Training Simulator (reference section 7.7). Instructional classes shall be provided, along with **Training Materials (DRD SW-17)**.

The contractor shall deliver any software models or programs used to simulate, analyze, and predict the performance of Flight Software algorithms. Examples of such programs are the Attitude Determination & Control Simulator used by the GN&C subsystem analysts to develop the algorithm requirements **(DRD SW-04)** and whose output is used to validate actual Flight software output. The format of these deliverables shall be as specified in the **Subsystem High-Level Software Simulator (DRD SW-18)**.

The contractor shall validate certain Flight software requirements through HRV I&T testing which includes, but is not limited to, assuring correct polarity, phasing, mechanism direction and symmetry, index positions, gains, scale factors, and some failure detection and correction actions.

The contractor shall ensure that both functional and performance test procedures, which execute the DM/EM flight hardware and flight software in all modes and configurations for which the contractor is responsible, are thoroughly exercised. These tests will be used to verify performance during initial integration, environmental testing, pre-ship at the spacecraft integration facility, post-ship at the launch facility, and on the launch vehicle. These tests shall be designed to execute as much of the flight software code and data as is possible in a l-g environment.

Once selected and approved by the Project, the default and baseline values for tables and parameters used in the Ground Test software and Flight software shall be placed under CM control.

The Acceptance phase shall be concluded when the contractor has delivered the software and responded to all action items from the successful Software Acceptance Review (SWAR) per **Software Review Packages (DRD SW-15)**.

7.2.4 Pre-Launch Sustaining Engineering through De-orbit Activities

Key members of the contractor's Flight software development team shall be designated to provide continued test and maintenance coverage of software following its delivery to the Spacecraft Integration and Test Team, Flight Operations Team, and the Project V&V Team. The same level of testing, V&V, QA, and Configuration Management (CM) monitoring that existed prior to the S/W Acceptance Review shall be applied during the generation of additional software releases or patches if they are required.

The contractor shall be responsible for anomaly resolution and the delivery of software modifications involving their delivered Flight and SDV software for the DM/EM through the end of the HST check-out following the Servicing Mission. The contractor shall be responsible for anomaly resolution and the delivery of software modifications involving their DM Science Operations and De-orbit software through the end of HST's mission.

The contractor shall deliver copies of the **Software Development Files (DRD SW-14)** for any EM flight software delivered.

7.3 Software Management Requirements

7.3.1 Software Management Organization

The contractor's organizational structure shall exhibit a managerial independence between the software development and V&V components.

The contractor's program organization (Org chart) shall recognize the system level aspects of flight software by its position with other DM subsystems. The contractor shall demonstrate that the software has a high level of independence and visibility within the management structure.

7.3.2 Resource Estimation and Allocation

Resource planning for the software elements shall include the contractor's participation in various technical working groups and interface meetings that relate to software, and support of NASA IV&V, as defined in section 7.4.1.

The contractor shall be solely responsible for the management of any sub-contractors or team members. The contractor shall be responsible for acquiring and including Software Measures (Metrics) from any sub-contractors or team members.

7.3.3 Software Measures (Metrics)

The contractor shall collect and report software measures supporting the analysis of both software product quality and schedule/effort/cost performance. The collection and reporting of metrics shall be automated to the fullest extent practicable. Measures shall be provided to the Project both as raw data and in graphical form. **Software Measures Report (DRD SW-16)** lists the minimum set of required measures.

7.3.4 Formal Software Reviews

Formal reviews (in accordance with the **DRD SW-15**) shall be conducted with Government participation. The HST Program Software Manager shall be a co-chair with the contractor. The Government shall provide a description of the review's success criteria at least one month in advance, and shall reserve the right to require a delta review if success criteria are not met.

7.4 Government Insight and Support of Government FSW Development

This section defines Government access to Flight Software documentation, data, and analysis to allow appropriate insight of development effort, including the NASA IV&V interface.

All contractor, sub-contractor, and team member reviews, audits, meetings and other activities pertinent to the execution of the contract shall be open to Government review/attendance. The contractor shall provide the Government with reasonable and timely notification, to facilitate Government attendance in person, by telecon, or by videocon. Other government HRV contractors may also attend these reviews, audits, and meetings at the government's discretion.

DRD documentation shall be accessible to the HRSDM Project via a web-based system with firewall and account/password protections.

7.4.1 NASA IV&V Support

The contractor shall ensure that all software documentation and code required for the NASA Software Independent Verification and Validation (IV&V) effort is made available to NASA IV&V personnel. Where electronic/web-based access to information is available to the HRSDM Project, the contractor shall also make access available to NASA IV&V. The contractor shall allow NASA IV&V review and participation before final product delivery to the government. The contractor shall respond to formally delivered issues from IV&V that are delivered from the HST Program's IV&V Liaison (typically the HST Program Software Manager).

7.4.2 HRSDM Project EM FSW Development and V&V Support

The contractor shall support the government's generation of the completed EM FSW image from the delivered contractor's EM image. The contractor's support shall consist of the deliverable documentation and training in the use of the software development environment, SDV software, and FDVF, as well as assisting with the evaluation and interpretation of FSW anomalies. The government may submit Software Problem Reports into the contractor's Software Problem Reporting system.

Beginning late in the Software Integration and Test Phase, the contractor shall begin supporting the independent system level testing performed by the HRSDM Project's V&V Team. This group will develop and execute their own system level tests on the contractor-delivered FSW Development & Validation Facility (FDVF). The contractor's support shall consist of assisting with the evaluation and interpretation of test results when requested, as well as with the analysis of software problems identified.

7.5 Software Maintenance

The contractor shall develop and maintain the DM Flight software and documentation to ensure reliability, maintainability and operability, along with the environments, emulators, and test software necessary to develop and verify these systems through the end of the HST mission.

7.6 Software Development, Validation, and Maintenance Environment

A software development, validation, and maintenance environment shall be used for the life cycle management of the DM/EM Flight Software and associated ground operational software. This environment shall contain the software, databases, compilers, debuggers, emulators, tools, and procedures/test scripts necessary to perform software management, design, development, local configuration management, testing, debugging, integration, verification & validation, maintenance, and preparation of software images in a format(s) suitable for both loading in a ground test configuration and uplinking to HRV. This includes a complete test environment to validate any Flight Software modifications. Also included in this environment is the test bed facility used for real-time, closed loop testing on flight-like hardware (see next section). The software portion of this environment shall be a deliverable in accordance with the **Software Development and Validation Software Releases (DRD SW-21)**.

The contractor shall provide a Ground Reference Image of the executable code in PROM and EEPROM (if applicable) on the spacecraft as well as the Flight Software in use on board at acceptance, should they be different (i.e., any patches or operational uploads required to get to the acceptance baseline).

7.7 Software Development & Validation Facility (SDVF)

The contractor shall provide all resources necessary to develop, certify, and maintain the real-time closed loop test bed facility. The SDVF (test bed facility mentioned in 7.6) consists of the hardware and software systems used to accurately simulate the on-board HRV environment in which the Flight Software will operate. The test bed shall contain engineering model (h/w) units of necessary flight hardware (including the flight microprocessor) as well as dynamic software models comprising the remainder of the HRV and the necessary on-orbit environment. The SDVF shall also contain the same ground system that is used for the HRV Integration & Test program. The SDVF shall be certified and delivered (in place) to the contractor's flight software team for flight software testing and V&V.

Two additional exact copies of the SDVF shall be developed, certified and delivered by the contractor. The FSW Development & Validation Facility (FDVF) shall be delivered to the government for development and validation of EM FSW applications and Flight Software Project V&V. Another copy (called the HRV Training Simulator) shall be delivered to the Operations Control Center (OCC) to act as a spacecraft simulator for OCC software checkout, HRV command procedure checkout, and Flight Operations Team training. See the additional requirements for the SDVF/FDVF/Training Simulator in the Requirements Specification. The contractor shall provide the **SDVF/FDVF/Training Simulator Specification (DRD SW-23)** and **SDVF/FDVV/Training Simulator Drawings, Wiring, and Parts List (DRD SW-24)** for long-term maintenance.

The contractor shall be responsible for maintenance of the special hardware (non-commercial such as C&DH avionics and power supplies) in the three facilities for the duration of the HRV mission (through HST de-orbit). The HST Program shall be responsible for any commercial hardware (e.g. workstations, bus monitors) in the FDVF and Training Simulator beginning when HST science operations resume following servicing.

8.0 Integration, Test, and Verification

8.1 System Assembly and Integration

The contractor shall perform the effort necessary to integrate and validate all DM flight hardware and software and verify all requirements applicable to them. The DM shall be integrated with all its component flight hardware and its functionality shall be verified prior to environmental testing. The contractor shall provide for rework and retest of the DM components that it supplies as part of this contract. The contractor shall provide all resources required for DM Assembly and Integration.

8.2 System Test

The contractor shall examine and analyze the verification requirements delineated in the **HRSDM System Verification Plan (TBD)** and other applicable documents to define the tests and analyses needed to verify DM-specific requirements. The contractor shall determine the resources needed, develop schedules, develop and execute test plans and procedures, accumulate, reduce, and manage test data, prepare and document predicted test results, develop pass/fail criteria, prepare test summary reports, document anomalies, and assign, track and document closure of action items. The contractor shall make necessary changes to DM designs and operational procedures as a result of the tests and analyses performed. Test data shall be archived. Test data shall be made available to the Government upon request.

The DM I&T plans, procedures and schedules shall be documented in the **DM I&T Plan (DRD DM-03)** and provided to the HST Program for approval prior to their implementation. Subsequent to Government approval, the contractor shall implement the plan described in **DRD DM-03** and qualify the DM. The contractor shall conduct and document a DM Test Readiness Review (TRR). The contractor shall provide the **Test Readiness Review (TRR) Package (DRD PM-41)**, and the **DM Test and Verification Reports (DRD DM-04)**.

The DM contractor shall provide the DM Ground Test Set (DMGTS) as described in section 13.3 for DM and mission I&T. This version will be a subset of the complete ground system and will include all the functionality of the flight-operations ground system applicable to mission-level I&T. The test conductors will support the contractor's integration of test procedures into the ground system. The contractor shall be responsible for integration of the test procedures into the ground system. The contractor shall provide all additional resources required to support the DM-specific aspects of DM and mission I&T.

The contractor shall manage and coordinate the resolution of problems or anomalies that affect the DM elements for which it is responsible, and report to the HST Program those problems or anomalies that it identifies in any other HST or HRSDM element and that could adversely affect the system. The contractor shall create and maintain an anomaly tracking and resolution system that is remotely accessible. Anomalies occurring during DM Integration and Test (I&T) shall be entered into this system and reported as they occur.

8.3 Mission-Level I&T

The contractor shall support the overall HRSDM Integration and Test phase that is expected to take place at the NASA Goddard Space Flight Center. The DM and all supporting equipment shall be delivered to the NASA GSFC, and personnel support provided during the HRSDM I&T activity. Launch support shall be provided at the launch site, as appropriate. The DM contractor shall provide a DM I&T Manager who will serve as the single point of contact for DM-specific I&T matters. This DM I&T Manager shall interface primarily with the HST Program HRSDM I&T Manager.

The contractor shall examine and analyze the requirements delineated in the **DM Specification (DRD DM-01)** and other applicable documents, and define the tests and analyses needed to verify these requirements at the mission level. The contractor shall participate in determining the resources needed, develop schedules, develop and execute test plans and procedures, accumulate, reduce, and manage test data, prepare and document predicted test results, develop pass/fail criteria, prepare test summary reports, document anomalies. The contractor shall assign, track and document closure of action items that are appropriate for its DM team.

The contractor shall provide the effort necessary to participate in mission I&T. The contractor shall make necessary changes to DM designs, I&T procedures and operational procedures as a result of the tests and analyses performed. The contractor shall provide the **DM Test and Verification Reports (DRD DM-04)** to document the Level 3 (DM) verification. Test data shall be archived. Test data shall be made available to the Government upon request.

8.3.1 DM to EM and HST Interface Tests

The contractor shall support three electrical and two mechanical interface tests prior to mission-level flight integration. These interface tests shall utilize breadboard and engineering test units to verify proper operation of EM and HST interfaces. These tests will be held as early as practical, at a time mutually agreeable to the contractor and NASA, so that there is sufficient time to correct problems uncovered by the test prior to mission-level integration.

8.3.2 DM Simulators

The contractor shall design, fabricate, test, and deliver a DM electrical simulator for use in EM development and HST operations. The contractor shall maintain, update, and support the operations of this simulator. The contractor shall deliver the **DM Electrical Simulator User's Manual (DRD DM-15)**. The design of the simulator shall be documented in the **DM Electrical Simulator Design Document (DRD DM-16)**.

The contractor shall design, fabricate, test, and deliver a thermal-mechanical DM simulator. The contractor shall maintain, update, and support the operations of this simulator. The contractor shall deliver the **DM Thermal-Mechanical Simulator User's Manual (DRD DM-08)**. The design of the simulator shall be documented in the **DM Thermal-Mechanical Simulator Design Document (DRD DM-09)**.

The Contractor shall provide a DM Simulator that provides the hardware and software necessary to produce all data types that the DM will transmit and provide appropriate responses to commands sent via the contractor Provided DM Test System. The system shall have the fidelity needed to verify the DM Test System and to train HST Operations Personnel for the Robotic Servicing Mission. The contractor shall provide 2 early versions of the Simulator to GSFC to support HST Ground System Integration and Testing. The contractor shall provide updates to the systems at GSFC during the DM development phase to meet GSFC Flight Hardware and Ground System Development and Test efforts. The contractor shall provide a simulator with the fidelity needed to train HST Operations Personnel for the Robotic Servicing Mission 18 months prior to the SM Launch Date. The DM contractor shall provide support to the HST Program for integrating the above system into the HST Ground System.

9.0 Mission Assurance

The contractor shall maintain a documented Mission Assurance Program. The program shall meet the requirements identified in HRSDM Mission Assurance Requirements SMR-5000.

The mission assurance program shall have sufficient staff and facilities to provide the required quality and reliability engineering, parts engineering, system safety, and materials control for the fabrication, integration, contamination control, calibration, and verification testing (including project test plans and environmental test plans) of the DM.

The contractor shall provide DM-experienced QA personnel resident at GSFC on delivery of the DM. The personnel will function as part of the HST quality team through launch.

The contractor shall provide the Government and its support contractors access to the reports, analyses, notebooks and working papers of the staff performing the analyses and assessments required by the HRSDM MAR.

10.0 Launch Support

NASA will provide standard payload processing facilities and services as GFE.

The contractor shall be responsible for technical and managerial integration with the HST Program of all DM aspects of the launch site activities. The launch site activities include HRV transportation at the launch site, HRV processing, testing, HRV/launch vehicle I&T, and launch. This work includes the design, manufacture and certification of any needed GSE. The HST Program is responsible for the overall management and conduct of the launch site activities.

The contractor shall participate in defining, implementing and maintaining a **HRSDM Launch Site Plan** describing how the HST Program will conduct operations at the launch site for HRV processing, launch vehicle integration and testing, and launch. The contractor shall develop and implement detailed procedures for DM launch site tests, handling and launch, and shall supply the necessary operations procedures to the HRV Ground System for use in launch support. The contractor shall support Flight Readiness Reviews (FRRs) with engineering and management data that ensure the HRV is ready for flight.

The contractor shall plan for enabling the HST Program to conduct the Launch Operations Readiness Test and the Flight Operations Readiness Test using, as practicable, the full HRV Ground System.

The Government will provide the transportation of the HRV (including required GSE and GFE) from the mission I&T facility to the launch site. The contractor shall develop DM-specific transportation requirements, plans and procedures. The contractor shall document this effort in the **DM and GSE Transportation Plan (DRD IT-02)**.

11.0 HST Interface

11.1 HST Battery Augmentation

The contractor shall include within the DM the necessary power conditioning circuits, battery capacity, harnessing, and connectors to interface to HST and augment the HST batteries as specified in the DM requirements as defined in section C.0. The contractor shall conduct and present analysis as specified in section 3.2.

11.2 HST Gyro Augmentation Support

The contractor shall include within the DM the necessary circuitry, harnessing, and connectors to interface between HST, the GFE gyro Electronic Conditioning Units, 1553 interface electronics, and the replacement gyros.

11.3 HST Mechanical Interface

The contractor shall mechanically interface to HST as specified in the DM requirements as defined in section C.0.

12.0 Ejection Module Interface

The Ejection Module (EM) houses all the replacement equipment required for the servicing activities, with the exception of the replacement battery subsystem and the ECU's and the control electronics for the replacement RSU's, which are housed in the DM.

The EM also houses the Grapple Arm (GA) and the Dexterous Robot (DR). The GA is used during the capture phase to effect docking, and the GA/DR combination is used for servicing operations.

After servicing operations are complete, the EM is ejected from the HST/DM mechanical system.

The contractor shall ensure that the DM to EM interfaces are compatible with all required HRSDM functions.

13.0 De-orbit Module Ground System Development

13.1 Ground Segment and Operations Management

The HST Program is responsible for the overall ground system and the integration and test of the HRV and HST ground systems. The contractor shall provide the technical and management oversight of all of the DM Ground Segment and Operations development support activities. This part of the contractor's management function shall coordinate all of its Ground Segment and Operations-specific activities, including planning, reviews and meetings, quality assurance, data and documentation.

13.2 Ground Segment and Operations Systems Engineering

The contractor shall perform the systems engineering tasks required to coordinate and integrate HRV and Ground Segment development and ensure compatible end-to-end system design. These tasks shall include the examination of HRV and Ground Segment designs in sufficient depth to identify and characterize physical, functional, or operational incompatibilities that exist or are anticipated, and the coordination of appropriate remedial actions through the HST Program. The contractor shall establish and maintain contact with the HST Program Ground Segment development organizations to coordinate joint or otherwise interrelated development activities.

The contractor shall participate in reviews of Ground Segment systems for which the HST Program is responsible [e.g., scheduling, command generation, real-time commanding & monitoring, trend analysis, orbit determination, and Project Data Base (PDB) creation, management and maintenance] in order to ensure end-to-end compatibility of the Ground Segment with the DM. The contractor shall create, deliver, and document the DM software, data and training needed to implement the above systems. The HST Program will define and conduct top-level systems analyses and trade studies pertaining to the Ground Segment and mission operations. The contractor shall participate in and support the aspects of these analyses pertaining to interaction with and use of the DM.

The contractor shall support the HST Program's development of the HRSDM operations concept. As part of this activity, the contractor shall define the capabilities of the DM elements they are responsible for and the manner in which they both support and impact HRV operations (e.g., target acquisition times, momentum management interfaces, and stability required characteristics for proximity operations). The contractor shall provide inputs for and support development of simulation scenarios for operations planning.

The contractor shall support HST Program technical reviews of the Ground Segment. The contractor shall support Ground System testing.

13.3 Ground System Hardware and Software

The contractor shall support the HRSDM team in integrating the DM with the HRV Ground System. The HST Program will be responsible for development and operation of the Ground Segment. The DM contractor shall provide the DM Ground Test Set (DMGTS) that will process all data types and formats that the DM will transmit and receives during all phases of the mission. The DMGTS shall provide a set of Application Program Interfaces (API) that will allow the Control Center System (CCS) to interface with it. The HST Program will manage the Ground Segment interface to the HRV.

The contractor shall provide DM-specific operations support for launch, on-orbit checkout, deployment, and servicing operations for the HRV.

13.3.1 Ground System DMGTS

The DM Contractor shall provide a DMGTS that provides the hardware and software necessary to command the DM/EM and monitor DM/EM telemetry. The DMGTS shall be able to receive and process all data types and formats that the DM will transmit during all phases of the mission. The DMGTS shall be able to process and transmit all command types and formats that the DM will receive during all phases of the mission.

The DMGTS shall be able to function as a standalone test system, supporting a minimum of 4 workstations, for performing all data processing and commanding that is required to support the EM/DM Flight Hardware and Software I&T test programs. The DMGTS shall provide a set of Application Program Interfaces (API) that will allow the HST Program to use the Control Center System (CCS) system to control it and extend the DMGTS's capabilities and produce an integrated system look and feel for the Flight Operations Team.

If the DMGTS is built from a contractor provided base system and not a HST CCS system, the DM Contractor will provide 3 early versions of the DMGTS to GSFC soon after the procurement is awarded.

The Contractor will provide updates to the systems at GSFC during the DM development phase to meet GSFC Flight Hardware and Ground System Development, Test and training efforts.

The DM Contractor shall provide support and training at GSFC to the HST Program for integrating the DMGTS into the HST Ground System.

The Contractor will provide a version of the DMGTS with the fidelity needed to train HST Operations Personnel for the Robotic Servicing Mission 18 months prior to the SM Launch Date.

13.3.2 Ground Segment Trade Studies

The HST Program will define and conduct top-level systems analyses and trade studies pertaining to the Ground Segment and mission operations. The DM Contractor shall support these trade studies to assess if the DM Ground Test System (DMGTS) should be built from a CCS test system or a Contractor provided base system.

The DM Contractor shall support trade studies to determine the configuration of the DMGTS and the HST Ground System that will be needed to provide the availability and reliability requirements that will be needed to support critical activities.

The DM Contractor shall support trade studies to determine if capabilities, beyond those needed for I&T, that are needed to support servicing and post servicing operations should be provided by the HST Ground System Team or the DM Contractor.

13.3.3 Ground System DMGTS Network and Security

All computer systems provided by the DM contractor shall comply with NPG 2810. The HST Program will provide all LAN connectivity at GSFC, network security at GSFC, and WAN connectivity to TDRSS and DSN ground stations.

13.3.4 Ground System TDRSS Scheduling

The DM Contractor shall provide the requirements that will be needed to add the scheduling of TDRSS forward and return links to the HST PASS scheduling system that will be needed to support DM direct operations.

The contractor shall design the DM to minimize post-servicing TDRSS scheduling of DM direct events. It is expected that the 1553 interface with HST will provide a path for housekeeping and routine commanding.

13.3.5 Ground System DMGTS Post-Servicing Support

The HST Ground System team will provide maintenance on the HST Ground Systems to include the DMGTS between the SM and de-orbit phases of the mission.

The DM Contractor shall provide support and training at GSFC to the HST Program for maintaining and upgrading the DMGTS.

13.3.6 Ground System DMGTS De-orbit Support

The contractor shall verify the integrity of the DMGTS prior to the de-orbit phase and, if needed, restore the system to an as-delivered state.

13.4 Ground Segment Mission-Level Operations and Mission Planning Support

The contractor shall provide to the PDB the algorithms, parameters, constants, system characteristics and documents needed to operate the DM. The operational information provided by the contractor shall include information that describes and enables the use of GA components to support docking operations. The contractor shall adhere to HST Program processes for certifying each PDB item's readiness for ground and/or flight use. Certification shall involve tests using engineering models, test facilities and simulators, as appropriate, prior to use with the flight hardware. Each element of the PDB to be used for post-launch HRV operations shall be certified for use within and by the HRV Ground Segment. The certification process shall be described in the **Project Data Base (PDB) Certification Plan (DRD OPS-01)**. In the **Project Data Base (PDB) Certification Reports (DRD OPS-02)**, the contractor shall provide readiness certification for each item of the DM to allow use with the flight hardware.

The contractor shall support the HST Program in the development of operations procedures, including definition of requirements for these procedures and review of procedures for completeness and safety. This support shall encompass all operations procedures including routine, contingency, and fault isolation procedures. The contractor shall support the testing of operations procedures and the training of operations personnel in the use of these procedures. The contractor shall co-locate staff at GSFC to support these activities and to support launch and servicing operations.

The contractor shall deliver DM commands and procedures for inclusion in the appropriate Ground System Database. Depending on the base system chosen to build the DMGTS, the database may or may not be in the PDB format that the CCS system uses. The contractor shall adhere to the HST PDB format for any data processed by a HST CCS system.

The contractor shall develop and provide, in a form compatible with the DMGTS, the commands, procedures, algorithms, and reference data required to command the DM, display telemetry, and trend the performance of the DM for all data that is sent directly from or to the DM.

The contractor shall develop and provide, in a form compatible with the CCS ground system, the commands, procedures, algorithms, and reference data required to command the DM, display telemetry, and trend the performance of the DM for all data that is received or sent through HST. The procedures, algorithms, calibration and reference data shall be defined in a **Reference Data Description Document (DRD OPS-03)**.

The contractor shall create and deliver the **Operations Handbook (DRD OPS-04),** which describes the DM subsystems and their functions, the subsystem operational modes, and DM and ground system operating guidelines.

The contractor shall create and deliver the **DM Constraints and Restrictions Document (CARD) (DRD OPS-05)** describing the limitations of DM components and describing the measures necessary to protect and ensure the safe use of the DM and its components.

The contractor shall create and deliver the **DM Operations Limitations Document (OLD) (DRD OPS-06)** documenting uses and configurations of DM components that are safe but can result in interruption of the mission timeline and/or loss of data.

The contractor shall support tests conducted by the HST Program during HRSDM I&T. These tests shall include the Ground System Verification and Validation (V&V) Tests and the End-to-End Data Flow V&V Tests.

13.5 DM Simulators and DM Operations Training

The contractor shall support the use of the simulators specified in Paragraph 7.7 and 8.3.2 for their described purposes. The contractor shall train HRSDM team personnel in the operation and maintenance of these simulators.

The contractor shall provide operations-oriented DM training to the HST Program. The contractor shall provide the **Training Scenarios and Training Course Materials Document (DRD OPS-08)**.

The contractor shall provide on-site support for all mission simulations in support of launch and early orbit operations, proximity operations and capture, the servicing mission and DM/HST de-orbit operations.

14.0 Mission Operations

The contractor shall develop a **Flight Procedures Handbook (DRD OPS-09)**, which includes nominal and contingency DM procedures for all phases of the mission.

The contractor shall support all operational phases of HRSDM and, subsequent to the servicing activity, shall support HST in the areas of sustaining engineering, software maintenance, and anomaly resolution.

The contractor shall also develop a **Flight System Description and Operations Manual (DRD OPS-07)**

15.0 Common Components

The contractor shall provide the government the opportunity to purchase additional common components (such as computers, sensors, etc.) for use in the EM.

D. ACRONYM LIST

ADD	Algorithm Design Document
CARD	Constraints and Restrictions Document
C&DH	Command and Data Handling
CCR	Configuration Change Request
CCS	Control Center System
CDR	Critical Design Review
CM	Configuration Management
COTS	Commercial Off-the-Shelf
DM	De-orbit Module
DMGTS	DM Ground Test System
DMP	Document Management Program
DR	Dexterous Robot
DRD	Data Requirements Document
EEPROM	Electrically Erasable Programmable Read-Only Memory
EGSE	Electrical Ground Support Equipment
ELV	Expendable Launch Vehicle
EM	Ejection Module
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPS	Electrical Power System
ETU	Engineering Test Unit
EVMS	Earned Value Management System
FPGA	Field-Programmable Gate Array
FRR	Flight Readiness Review
FSW	Flight Software
FVMF	Flight Software Validation & Maintenance Facility
GA	Grapple Arm
GFE	Government Furnished Equipment
GMM	Geometric Math Model
GN&C	Guidance, Navigation, and Control
GOTS	Government Off-The-Shelf
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HRSDM	Hubble Robotic Servicing and De-orbit Mission
HRV	Hubble Robotic Vehicle
HST	Hubble Space Telescope
ICD	Interface Control Document
I/O	Input / Output
IPT	Integrated Product Team
ISO	International Standards Organization
I&T	Integration and Test
IV&V	Independent Verification and Validation
LV	Launch Vehicle
MAR	Mission Assurance Requirements

MOR	Mission Operations Review
MOTS	Modified Off-The-Shelf
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis
OCC	Operations Control Center
OLD	Operations Limitations Document
ORR	Operations Readiness Review
OTS	Off-The-Shelf
PCS	Pointing Control System
PDB	Project Data Base
PDR	Preliminary Design Review
PROM	Programmable Read-Only Memory
PSR	Pre-Shipment Review
QMS	Quality Management System
RF	Radio Frequency
RGA	Rate Gyro Assembly
RGMM	Reduced Geometric Math Model
RMS	Remote Manipulator System
RTMM	Reduced Thermal Math Model
SDV	Software Development and Validation
SDVF	Software Development and Validation
SINDA	System Improved Numerical Differencing Analyzer
SI units	International System of Units
SM4	Servicing Mission 4
SMOV	Servicing Mission Observatory Verification
SMP	Software Management Plan
SOW	Statement of Work
SRR	Software Requirements Review
SRS	Software Requirement Specification
TCS	Thermal Control System
TMM	Thermal Math Model
TRR	Test Readiness Review
TSS	Thermal Synthesizer System
V&V	Verification and Validation
VDD	Version Description Document
WBS	Work Breakdown Structure

E. INDEX

Requirements Document

for the

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

June 1, 2004

TABLE OF CONTENTS

ACRONYMS

AB	Aft Bulkhead
AC	Alternating Current
AD	Aperture Door
AMD	Autonomous Mode Disable
AO	Atomic Oxygen
AR&C	Autonomous Rendezvous and Capture
ASCS	Aft Shroud Cooling System
ATP	Authority to Proceed
C&DH	Command and Data Handling
CCB	Configuration Control Board
CCR	Configuration Change Request
CEI	Contract End Item
Cg	Center of Gravity
COS	Cosmic Origins Spectrograph
COSTAR	Corrective Optics Space Telescope Axial Replacement
CSS	Coarse Sun Sensor
dB	Decibel
DBA2	Diode Box Assembly 2
dc	Direct Current
DM	De-orbit Module
DMCS	DM Communications System
ECU	Electronic Control Unit
EEE	Electrical, Electronic, and Electromechanical
ELV	Expendable Launch Vehicle
EM	Ejection Module
EMC	Electromagnetic Compatibility
EMCS	EM Communications System
EOD	End Of (orbit) Day
EOM	End-of-Mission
EON	End Of (orbit) Night
EPS	Electrical Power Subsystem
ERC	External Robot Compatible
EWR	Eastern Western Range
F	Force
FOV	Field of View
FSS	Flight Support System
FSW	Flight Software
G	Standard Gravity
GA	Grapple Arm
GEVS	General Environmental Verification Specification
GFE	Government Furnished Equipment
GIOE	Gyroscope Input/Output Electronics
GIU	Gyroscope Interface Unit

GN&C	Guidance, Navigation and Control
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HDBK	Handbook
HGA	High Gain Antenna
HOST	HST Orbital Systems Test
HRSDM	HST Robotic Servicing and De-orbit Mission
HRV	HST Robotic Vehicle
HST	Hubble Space Telescope
Hz	Hertz
I/O	Input/Output
ICD	Interface Control Document
IRD	Interface Requirements Document
Kb	Modal gain
KHB	KSC Handbook
KSC	Kennedy Space Center
lb	Pound
LGA	Low Gain Antenna
LT	Load Transformation
LV	Launch Vehicle
M	Moment
MIL	Military
MIL-STD	Military Standard
MLI	Multi-Layer Insulation
NASA	National Aeronautics and Space Administration
NCS	NICMOS Cooling System
NHB	NASA Handbook
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NPD	NASA Policy Directive
ORI	Orbital Replacement Instrument
ORU	Orbital Replacement Unit
OTA	Optical Telescope Assembly
PA	Payload Adapter
PAF	Payload Attach Fitting
PCS	Pointing Control System
PDU	Power Distribution Unit
PFR	Portable Foot Restraint
PPL	Preferred Parts List
PSD	Power Spectral Density
PSEA	Pointing and Safemode Electronics Assembly
psi	Pounds per square inch
RF	Radio Frequency
rms	Root Mean Square
RSU	Rate Sensor Unit
SA	Solar Array

SEU	Single Event Upset
SI	Scientific Instrument
SM	Servicing Mission
SPDM	Special Purpose Dexterous Manipulator
SSE	Space Support Equipment
SSM	Support Systems Module
ST	Space Telescope
STS	Space Transportation System
TBD	To Be Determined
TBR	To Be Resolved
TBS	To Be Supplied
TDRSS	Tracking and Data Relay Satellite System
TRL	Technology Readiness Level
WF/PC II	Wide Field Planetary Camera II
WFC3	Wide Field Camera 3

	TBD/TBR List				
Item No.	**Section No.**	**TBD/TBR**	**Description**	**Responsible Party**	**Due Date**
	2.0	TBD	Mass Properties Status Report Document#	NASA	PDR
1.	3.2.1.1	TBR	Uncontrolled body rates up to 0.22 Deg/Sec/axis	NASA	ATP
2.					
3.	3.2.3.2	TBD	Servicing video observation – resolution and frame rate	NASA	PDR
4.	3.3.1.3.1.1	TBD	Figure 3-6 HST SA3 and HGA Sweep Volumes (TBD)	NASA	ATP
5.	3.3.1.3.3	TBD	DM clearance to connectors P105 and P106	NASA	SRR
6.	3.3.1.5.1	TBD	Main (J101) umbilical actuator envelope size	NASA	ATP
7.	3.3.1.5.2	TBR	Main (J101) umbilical actuator weight lbs.	NASA	ATP
8.	3.3.1.6	TBR	GIU mechanical interfaces drawing	NASA	PDR
9.	3.3.1.6.1	TBD	GIU Mechanical Envelope	NASA	PDR
10.	3.3.1.6.2	TBR	GIU weight is 25 lbs	NASA	PDR
11.	3.3.1.6.3	TBD	Intermediate in-line interfaces between ECU and RSU		
12.	3.3.1.6.4	TBR	Wire gauge size of 20	NASA	SRR
13.	Table 3-6 – Table 3-11	TBD	GIU Pin out Tables	NASA	PDR
14.	3.3.1.8	TBR	HST486 Mating half connector P/N	NASA	SRR
15.	3.3.1.9	TBR	GIU to 1553 Connector Mating half	NASA	SRR
16.	3.3.1.11	TBD	HRV to HST Connector layout	NASA	PDR
17.	3.3.1.11	TBD	The location of the connector interface plate	DM	SRR
18.	3.3.1.17.1.1	TBD	FOV CCS-4	NASA	SRR
19.	3.3.1.17.1.2	TBD	Shutter not completely light-tight and detector sensitivity to wave length		
20.	3.3.2.1.1	TBD	Liftoff static loads to b) P101 main umbilical actuator to TBD g.	NASA	ATP
21.	3.3.2.1.2	TBD	Random Vibration limits to b) P101 main umbilical actuator to TBD g RMS	NASA	ATP
22.	3.3.2.1.4	TBD	GIU vent location per drawing	NASA	PDR
23.	3.3.2.1.5	TBD	Shock loading due to ELV separation document	NASA	PDR
24.	3.3.2.1.6	TBD	ELV Resonant Frequency Constraints document	NASA	PDR
25.	3.3.2.2.6.1	TBD	a) GIU to pyro shock loads	NASA	PDR
26.	3.3.2.2.6.1	TBD	b) P101 main umbilical actuator to pyro shock loads	NASA	PDR
27.	3.3.2.3	TBR	Minimum first rigid body mode of 9hz	NASA	SRR
28.	3.3.2.3.2	TBD	Minimize SA3 excitement frequencies	NASA	SRR
29.	3.3.2.5.1	TBR	Liquid slosh – maximum modal gains	NASA	SRR
30.	3.3.3.1.1	TBD	Maximum effective thermal conductance at 3 berthing pin attachment points is TBD watt/°C	NASA	SRR
31.	3.3.3.1.2	TBR	Cable effective conductances (K) are less	NASA	SRR

	TBD/TBR List				
Item No.	Section No.	TBD/TBR	Description	Responsible Party	Due Date
			than or equal to 0.1 watt/°C		
32.	3.3.3.1.4	TBR	GIU surface properties are (α/ε) 0.96/0.87	NASA	SRR
33.	3.3.3.1.4	TBD	Surface properties of: b) P101 main umbilical actuator	NASA	SRR
34.	3.3.3.1.4	TBR	GFE thermal capacity of GIU is 3.46 BTU/°F	NASA	SRR
35.	3.3.3.1.4	TBD	GFE thermal capacity of b) P101 main umbilical actuator	NASA	SRR
36.	3.3.3.1.5	TBR	Operational Temperature limit of GIU is -24 to 60°C	NASA	SRR
37.	3.3.3.1.5	TBD	Operational temperature limit of b) P101 main umbilical actuator to between TBD	NASA	SRR
38.	3.3.3.1.5.1	TBD	Thermal Power	NASA	SRR
39.	3.3.3.1.5.2	TBD	Thermal Power Mode Definitions	NASA	SRR
40.	3.3.3.1.5.3	TBD	Thermal Power Mode Constraints	NASA	SRR
41.	3.3.3.1.5.4	TBD	Normal Science Mission Thermal Power Configuration	NASA	SRR
42.	3.3.3.1.6	TBR	GFE non-operational - Temperature Range of GIU to between -45 to 60°C	NASA	SRR
43.	3.3.3.1.6	TBD	GFE non-operational - HRV temperature b) P101 main umbilical actuator to between TBD	NASA	SRR
44.	3.3.3.3.5	TBR	Total mass fluence during AR&C limited to 3.6e-8 g/cm2	NASA	SRR
45.	3.3.3.6	TBR	Orbital debris flux model as defined in NASA TM-100-471	NASA	SRR
46.	3.3.4.2	TBR	300 Amp hour of battery capacity	NASA	SRR
47.	3.3.4.6	TBR	Switching devices compliance with TBD	NASA	PDR
48.	3.3.4.9	TBD	HRV shall provide power for b) P101 main umbilical actuator up to TBD watts	NASA	PDR
49.	3.3.4.9	TBR	HRV shall provide power for a) GIU 20 watts	NASA	PDR
50.	3.3.4.10.2	TBD	Grounding of Interfaces, Multi-layer Insulation (MLI)	NASA	PDR
51.	3.3.4.10.3	TBD	Grounding of Interfaces, Non Conductive Surfaces	NASA	PDR
52.	3.3.4.11.1	TBD	HRV Power Bus Ripple and Noise	NASA	SRR
53.	3.3.5.7	TBR	Propulsion – 50m safety zone during inspection and rate determination	NASA	SRR
54.	3.3.5.7	TBR	Propulsion – 5m safety zone during robot arm deployment and capture	NASA	SRR
55.	3.3.6	TBD	Instrumentation and Communication Interfaces	NASA	SRR
56.	3.3.6.1	TBD	Command Types	NASA	PDR
57.	3.3.6.2	TBD	Command Formats	NASA	PDR
58.	3.3.6.3	TBD	Command Signal Characteristics	NASA	PDR
59.	3.3.6.4	TBD	Differential Signals	NASA	PDR
60.	3.3.6.5	TBD	Data Interface	NASA	PDR
61.	3.3.6.5.1	TBD	Data Functions and Characteristics	NASA	PDR

	TBD/TBR List				
Item No.	**Section No.**	**TBD/TBR**	**Description**	**Responsible Party**	**Due Date**
62.	3.3.6.5.2	TBD	Data Formats and Timing	NASA	PDR
63.	3.3.6.5.3	TBD	Data Transfer Rates	NASA	PDR
64.	3.3.6.5.4	TBD	Data Input Interface	NASA	PDR
65.	3.3.6.5.5	TBD	Timing Interface	NASA	PDR
66.	3.3.7	TBD	EVR Interfaces	NASA	PDR
67.	3.3.7.1	TBD	Restricted Zones	NASA	PDR
68.	3.3.7.2	TBD	EVR Temporary Stowage	NASA	PDR
69.	3.4	TBD	Launch Vehicle to HRV Interfaces	NASA	PDR
70.	3.5	TBD	DM to EM Interfaces	NASA	SRR
71.	3.7	TBD	HRV to ORI/ORU and Dexterous Robot Interfaces ICDs	NASA	PDR
72.	3.7.3.2.2	TBR	Radial SI Magnetic Fields: A/B/C – 6 gauss	NASA	PDR
73.	4.1.1.4.1	TBR	Table 4-1 Limit load factors for HRV components	NASA	SRR
74.	4.1.1.4.4	TBD	Acoustic Load test level per ELV users guide document	NASA	PDR
75.	4.1.1.4.5	TBD	Maximum pressurization rate defined in ELV users guide document	NASA	PDR
76.	4.1.1.4.5	TBR	Figure 4-2 ELV depressurization plots	NASA	PDR
77.	4.1.1.4.7	TBR	On-orbit installation loads < 100 lbs	NASA	SRR
78.	4.1.1.4.7	TBR	Table 4-3 HST PFR limit load capability	NASA	SRR
79.	4.1.1.4.8	TBD	Robot induced loading Forces and Moments	NASA	PDR
80.	4.1.1.5.2	TBR	All pressurized components comply with MIL-STD-1522	NASA	PDR
81.	4.1.1.9	TBD	HRV Mass Properties Control Plan SMR-5091	NASA	PDR
82.	4.1.1.11.1.1	TBD	HRV Connector support bracket connections	NASA	PDR
83.	4.1.1.11.1.3	TBR	Instructional labels	NASA	PDR
84.	4.1.1.11.1.3	TBR	Protect against accidental activation/deactivation	NASA	PDR
85.	4.1.2.2.1	TBR	Load Capability of 3263 + 150 Watts		
86.	4.1.2.7	TBD	For EMC, use GEVS-SE for 120 VDC to robot	NASA	SRR
87.	4.1.3.1	TBR	Conductive transfer of heat between DM & HST < 10 Watts	NASA	SRR
88.	4.1.3.3	TBR	Minimum 12 hours in +V3 sun pointing attitude before transport	NASA	PDR
89.	4.1.3.3	TBR	ERC tool temp range –10 Deg C to +100 Deg C	NASA	PDR
90.	4.1.4.1	TBR	Rate null after separation in 100 minutes	NASA	PDR
91.	4.1.6	TBD	Pyrotechnic	NASA	PDR
92.	4.1.7.3	TBR	Vapor Pressure for lubricants < 10E-7 torr	NASA	PDR
93.	4.3	TBD	EM Design requirements	NASA	PDR
94.	4.4	TBD	Robot Arm Design Requirements	NASA	PDR
95.	5.10.3	TBS	Watchdog time rate	DM	PDR
96.	5.12.2	TBS	Dwell tables and addresses	DM	PDR

	TBD/TBR List				
Item No.	Section No.	TBD/TBR	Description	Responsible Party	Due Date
97.	5.12.2	TBS	Dwell table sample rate-Hz	DM	PDR
98.	5.13.1.6	TBD	Resolution bit of a specified time and FSW stored commands in seconds		
99.	5.13.2.1	TBS	number of absolute-time stored command sequences concurrently	NASA	PDR
100.	5.13.3.1	TBS	number of relative-time stored command sequences concurrently	NASA	PDR
101	Fig. 6-1	TBD	DM Conceptual Block Diagram		
102	6.3.1.4.1	TBR	Null rate accomplished in 100 minutes.		
103	6.3.2.3.1	TBD	HRV coordinate system		
104	6.3.3.7.3	TBR	The DM grounded to the HST by less than or equal to 10 Milliohms		
105	6.3.4.3.2.3	TBD	GIU Characteristics specification document		
106	6.3.5.1.2	TBR	Tipoff rates that are less than or equal to: V1<=0.138 degrees/sec, V2<=0.103 degrees/sec, V3<=0.132 degrees/sec		
107	6.3.5.2.2	TBD	Loads imparted by the DM to the EM during EM ejection shall not exceed		
108	6.3.6.4.1	TBD	DM shall have a minimum first rigid body mode of 20 Hz		
109	6.3.6.4.2.1	TBR	Appendage on the DM shall have a Kb of <= 0.04 (0 to 1 Hz), and <= 0.02 (> 1 Hz)		
110	6.3.6.4.2.2	TBR	Propellant "slosh" on the DM shall have a Kb of <= 0.02 (0 to 1 Hz), and <= 0.01 (> 1 Hz)		
111	6.3.6.4.5	TBR	HST Aft Shroud LGA coverage below 95% and communication signal strength by 1.7 dB		
112	Table 7-1	TBD	Verification Compliance Matrix		

1. INTRODUCTION

1.1 GENERAL

This Contract End Item (CEI) Specification establishes the requirements for the design, performance, and verification of the Hubble Space Telescope (HST) Robotic Vehicle (HRV), which will be launched from an Expendable Launch Vehicle (ELV) and will Autonomously Rendezvous and Capture (AR&C) with the HST.
For the purpose of this document, autonomous is defined as the independent or self-directed execution of a sequence of commands with Authority to Proceed (ATP) points to be confirmed by ground operations where the complete independent set of commands and ATPs would define an operational or mission phase (e.g., pursuit or capture). For the purpose of this document, the capture phase includes docking the HRV to HST.

The primary requirement of the HRV is to provide a controlled re-entry capability to the HST. Throughout this document, wherever the requirement for De-orbit or controlled re-entry is specified, the contractor may, with the concurrence of the Contracting Officer, utilize an alternate method of HST disposal, in accordance with NPD 8710.3B (perigee > 2,500 km, Apogee < 35,288
km). In no case shall the capability for an alternate disposal affect other requirements of this document. The secondary requirement is to extend the scientific life of HST with a focus on battery and gyroscopic augmentation. This includes ensuring that the scientific performance of the observatory is not degraded by adding these capabilities, i.e. "Do no harm". In the event of an unanticipated or unlikely contingency case, providing the controlled re-entry capability takes precedence over all HRV life-extension requirements. The HRV shall be able to accomplish its objectives during all phases of its mission independent of the operating state of the HST. This includes: pursuit, proximity operations, capture, servicing, and de-orbit operations.

The HRV shall provide additional HST life extension, capability for change out of enhanced Orbital Replacement Instruments (ORIs)/ Orbital Replacement Units (ORUs) and safely dispose of the HST at the end of its science mission. The HRV, see Figure 1-1, consists of: 1) a De-orbit Module (DM), which provides HRV control functions during pursuit, proximity operations, capture, and servicing (including controls for the grapple arm and robot), the AR&C sensor suite, and the HST controlled re-entry propulsion and control system; 2) an Ejection Module (EM), which provides the a) Launch storage for the ORIs/ORUs and the robot, b) the grapple arm mechanical and electrical interfaces, c) pursuit, proximity, capture, and servicing Guidance Navigation and Control (GN&C) actuators including propulsion, and d) EM disposal propulsion and GN&C system; 3) a grapple arm for the capture of HST at either grapple fixture, docking and robotic servicing; and 4) a robot for servicing implementation.

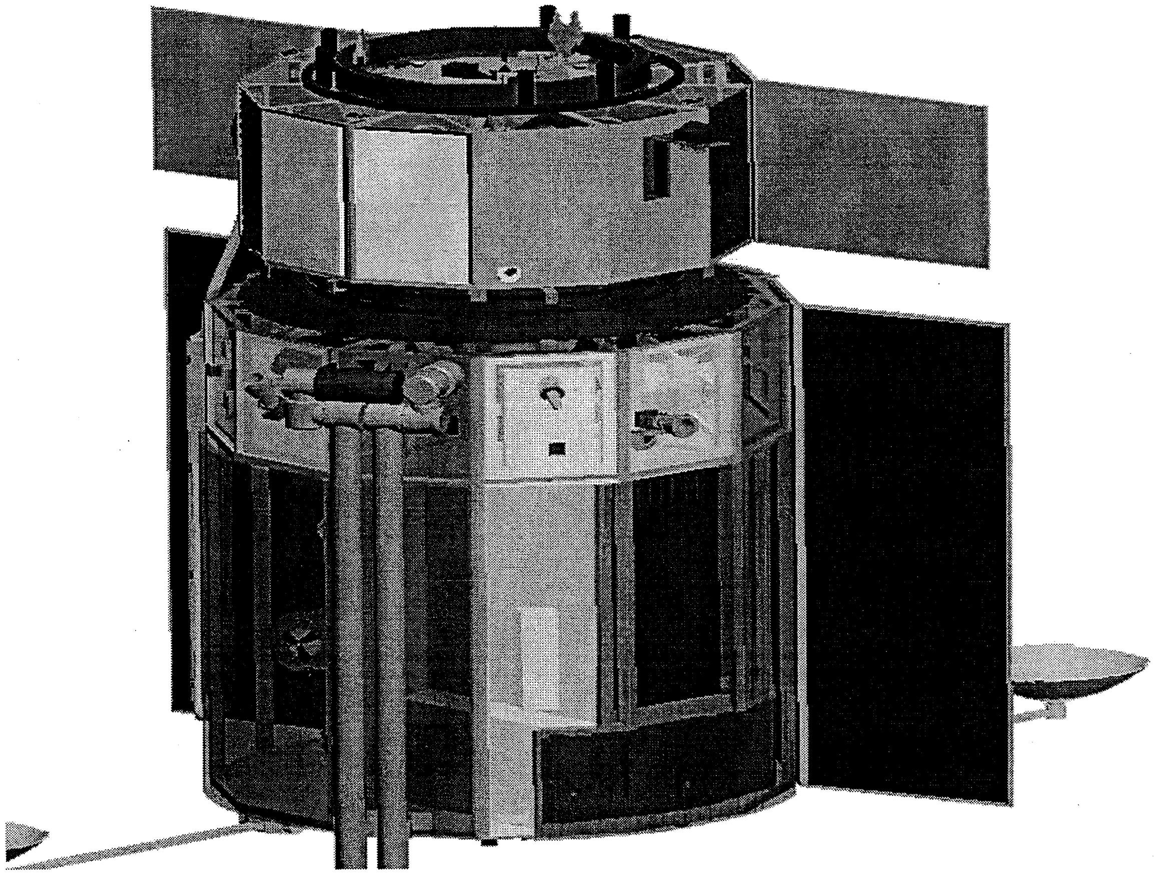


Figure 1-1. HRV Concept

1.2 ORGANIZATION

This document is a compilation of hardware requirement and interface control documents that pertain to the HRV mission. It is structured from the HRV requirements flowdown as shown in Figure 1-2. This document has been divided into the following sections: 1.0 Introduction, 2.0 Applicable Documents, 3.2 Level II/III System Requirements, 3.3 to 3.7 Interface Controls, 4.0 Design Requirements, 5.0 Flight Software (FSW), 6.0 DM Design Requirements, and 7.0 Verification. All interface control sections, 3.3 through 3.7, provide design definition that will be developed collaboratively with the DM contractor. Therefore, it is provided as information, unless specifically referenced within the requirement sections.

Sections 3 through 5 address interface controls and requirements by discipline function (i.e. mechanical, electrical, thermal, etc.), whereas section 6.0 identifies DM requirements by HRV mission phase. Therefore, Section 6.0 has some duplication of requirements.

For procurement purposes, this document has combined many documents identified in Figure 1-2 into this one document. The following is the order of precedence for this procurement document:
1) Section 3.2, Level II and III System requirements;
2) Section 6.0 DM Design Requirements;
3) Section 5.0 Flight Software;
4) Section 4.1 HRV Design Requirements;
5) Section 3.3 through 3.7 Design definition.

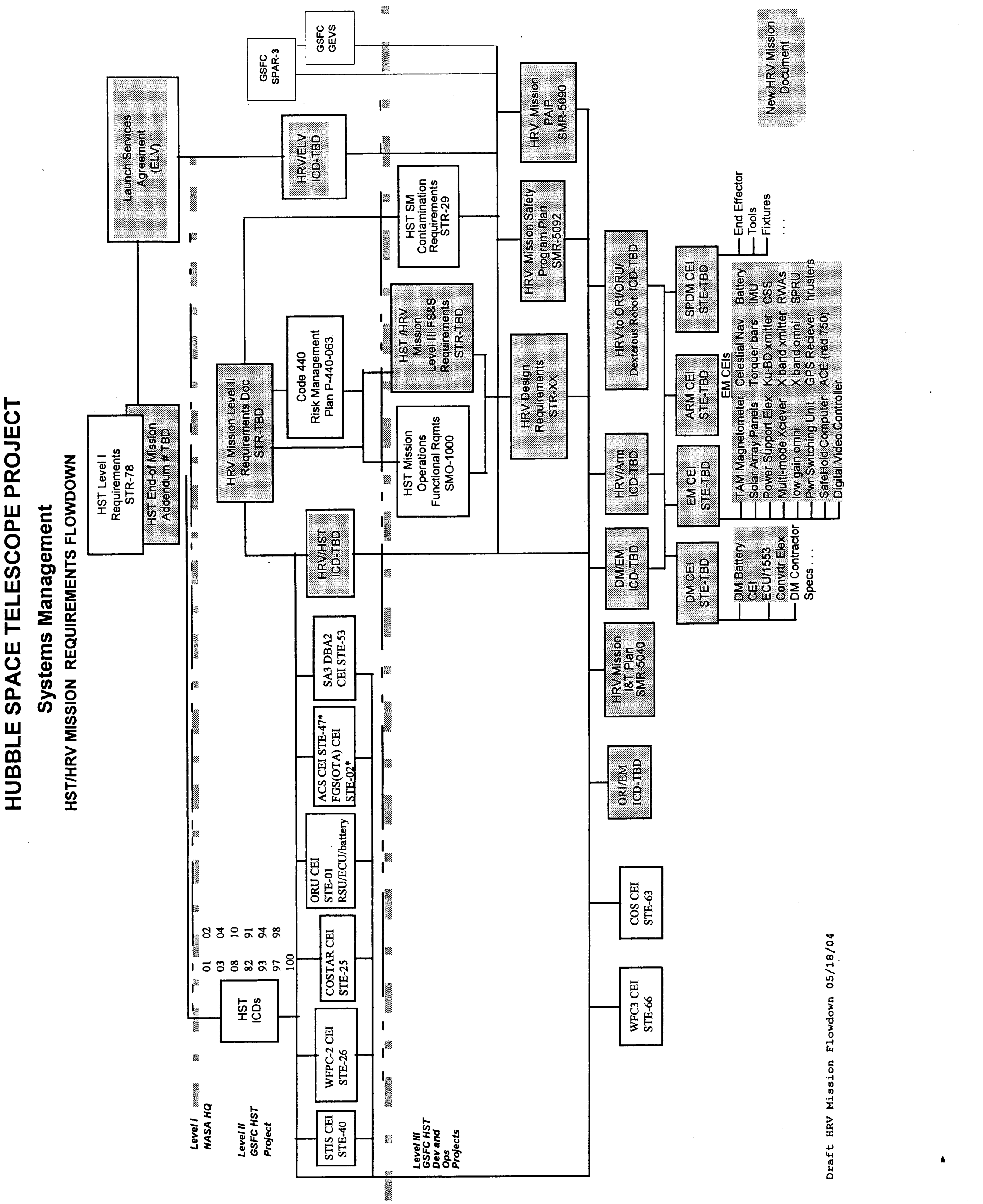


Figure 1-2 HST/HRV Mission Requirements Flowdown

1.3 CONTENT STATUS

The information contained in this document represents the current definition of the performance requirements for the HRV in all areas except where noted by a To Be Determined (TBD) or To Be Resolved (TBR). TBD indicates that the information required is not available, even in preliminary form. TBR indicates that the information is the best available at the time but final details remain to be resolved.

1.4 DOCUMENT CHANGE PROCEDURE

Once this document is baselined, any changes, including the removal of a TBD or TBR must be done formally. This requires that a Configuration Change Request (CCR) be processed through the HST Configuration Control Board (CCB).

2. APPLICABLE DOCUMENTS

The following documents, of the issue shown, form a part of this specification to the extent referenced herein. Within the text of this specification, applicable documents are referenced by their basic number only.

DOCUMENT NO.	TITLE
540-PG-8715.1.1	Mechanical Systems Center Safety Manual Volumes 1 & 2
EEE-INST-002	Instructions for EEE Parts Selection, Screening, Qualification and Derating
EM: FS&S 1483	HST Mechanism Design Reqts. & Guidelines
EWR 127-1	Eastern and Western Range (EWR) 127-1 Range Safety Requirements
GEVS-SE Rev A	General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components
GSFC-(PPL)-21	GSFC Preferred Parts List
GSFC-731-0005-83B	General Fracture Control Plan for Payloads Using the STS
GSFC S-313-100 Rev. A	GSFC Fastener Integrity Requirements
HRV-DR-ICD	ICD for the Hubble Robotic Vehicle Dexterous Robot
HRV-GA-ICD	ICD for the HST Robotic Vehicle (HRV) to Grapple Arm (GA)
IPC-2221	Generic Standard on Printed Board Design
IPC-2222	Sectional Design Standard for Rigid Organic Printed Boards
IPC-2223	Sectional Design Standard for Flexible Printed Boards
IPC A-600	Acceptability of Printed Boards
IPC-6011	Generic Performance Specification for Printed Boards
IPC-6012	Qualification and Performance Specification for Rigid Printed Boards
IPC-6013	Qualification and Performance Specification for Flexible Printed Boards
KHB 1700.7	
MIL-B-5087B	Bonding, Electrical, and Lightning Protection for Aerospace Systems
MIL-B-7883 Rev. C	Military Spec Brazing of Steel, Copper, Copper Alloys, Nickel Alloys, Aluminum and Aluminum Alloys
MIL-C-17 Rev. F	Cables, Radio Frequency, Flexible & Semi-rigid
MIL-C-27500	
MIL-C-38999	Connectors, Electrical, Circular, Miniature
MIL-C-39012	Connectors, Coaxial or Plug, Electrical

DOCUMENT NO.	TITLE
MIL-H-38534 Rev. B	Military Spec. Hybrid Micro-circuits, Gen. Spec for
MIL-HDBK-5G	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-P-55110 Rev. E	Military Spec. Printed Wiring Boards
MIL-STD-461A/3	Mil. Std. Electromagnetic Interference Characteristics, Req. for Equipment
MIL-STD-462 Rev. D	Mil. Std. Measurement of Electromagnetic Interference Characteristics
MIL-STD-975 Rev. K	Electrical, Electronic and Electromechanical (EEE) Parts List
MIL-STD-1246 Rev. B	Mil. Std. Product Cleanliness levels & Contamination Control
MIL-STD-1522A	Safe Design and Operation of Pressurized Missile and Space Systems
MIL-STD-1791	
MIL-W-22759	Mil. Spec. Sheet, Wire, Electrical,
MIL-W-81381	
NPD 8710.3B	NASA Policy Directive for Limiting Orbital Debris Generation
NASA TM 100-471	Orbital Debris Environment for Spacecraft Designed to Operate in Low Earth Orbit
NASA TMX-73331 Rev A	Natural Environment Design Requirements for the Space Telescope
NASA-STD-5005	NASA, Design Criteria Standard, Ground Support Equipment
NASA-STD-8719.9	NASA Standard for Lift Devices and Equipment
NASA-STD-8739.1	Workmanship standards for Staking and Conformal Coating of Printed Wire Boards and Electronic Assemblies
NASA-STD-8739.2	Workmanship standards for Surface Mount Technology
NASA-STD-8739.3	Soldered Electrical Connections
NASA-STD-8739.4	Crimping, Interconnecting Cables, Harnesses, and Wiring
NHB 5300.4	
NPR 6000.1E	Requirements for Packaging, Handling and Transportation for Aeronautical and Space Systems' Equipment and Associated Components
SCM-1020 Rev D	HST Flight Projects Configuration Management Plan
SE-04	HST Mass Properties Report
SMR-5000	HRV Mission Assurance Requirements
SMR-5091	HRV Mass Properties Control Plan
ST-ICD-02 Rev E	Axial SI to OTA and SSM ICD

DOCUMENT NO.	TITLE
ST-ICD-03 Rev F	Radial SI to OTA and SSM ICD
ST-ICD-91	Axial SI to SSE ICD
STR-29	HST Servicing Mission Contamination Requirements
STR-78	HST Level I Requirements for the Operational Phase of the HST Program
STR-81 Rev. A	HST Third Servicing Mission Level 3 FS&S Requirements
ST/SE-TBD	HRV Mass Properties Status Report
STR-125	HST SM4 Level II Requirements
STR-126	
4171550	HST Assembly Complete
4171580	BASIC CONFIGURATION & ALIGNMENT DRAWING SMM ASSY & ST
4171583	Grapple Fitting Assembly Starboard
4171590	Aft Shroud Assembly Complete
4171599-501	UMB Retract Mech – Inst of
4171776-003	Rate Gyro Assembly – Electronic Control Unit
4175650-501	BERTHING TARGET FSS CCTV
4175788	Tower, Umbilical, - FSS
4175792	Berthing Pin Assembly
4176429	Rate Gyro Assembly – Electronic Control Unit
4177051	Grapple Fitting Assembly Port
4177659	Hubble Space Telescope Inboard/Outboard Profile
GE 1525373	External Mech. I/F HST to HRV
GE 2021299	HST Advanced Computer ORU Assembly Drawing
GE 2044728	Envelopes, ASCS/NCS Conduit to HST
96337201000	FSS Interface Gauge Assy HST

3. REQUIREMENTS

3.1 SYSTEM DESCRIPTION

The function of the HRV is to provide additional life extension of high probability failure items and safely dispose of the HST at the end of its science mission. Life extension shall be achieved through robotic ORI/ORU change out and/or augmentation. HST safe disposal shall be provided by a controlled re-entry to Earth that meets the conditions of NASA NPD 8710.3 at the end of HST's science mission.

The HRV consists of two modules, 1) a De-orbit Module (DM), which provides the AR&C and the disposal propulsion and control system; 2) an Ejection Module (EM), which provides a) Launch storage for the ORIs/ORUs and the robot, b) the grapple arm mechanical and electrical interfaces, c) a propulsion and control system for pursuit and docking and d) EM disposal propulsion and control system; 3) a grapple arm for access to the HST for robotic servicing; and 4) a robot for servicing implementation.

The ORU/ORIs and robot (Government Owned Equipment (GOE)), are stowed in the EM, from launch until they are needed during the servicing mission phase (except the Electronic Control Units (ECUs)). The grapple arm is attached to the EM and stowed for launch. Instruments removed from HST during the servicing phase will be stowed in/on the EM. Government Furnished Equipment (GFE) items housed within the DM include: Gyro Interface Units (GIUs) and the main mechanical umbilical actuator (P101). The batteries that provide HST power augmentation are in the DM.

The grapple arm uses a Latching End Effector (LEE) to capture either of the two HST grapple fixtures. The arm then positions and aligns the DM with the HST Aft Bulkhead (AB) Flight Support System (FSS) Berthing Pins. The HRV then mechanically mates with the HST at the FSS Berthing Pins. Once the HRV is mated to the HST, the grapple arm extracts the robot from the EM. The robot then starts the process of HST ORU/ORI augmentation/servicing.

Baseline servicing activities include:

1. Connecting the HRV batteries in parallel with the HST EPS at the Solar Array (SA) Diode Box Assembly 2 (DBA2) interface to provide HST Battery Augmentation;
2. Removing the Wide Field/Planetary Camera II (WF/PC II) instrument and replacing it with the Wide Field Camera 3 (WFC3) Science Instrument (SI) which includes the three gyro Rate Sensor Units (RSUs), each housing two rate sensors, for gyro augmentation;
3. Replacing the HST Corrective Optics Space Telescope Axial Replacement (COSTAR) instrument with the Cosmic Origins Spectrograph (COS) instrument.

Each RSU mounted on the WFC3 instrument provides vehicle rate data to and is controlled by their associated ECU mounted in the DM. Data from the ECU is ultimately processed by the HST486 spacecraft computer as input to the HST Pointing and Control System (PCS). This new combination instrument connects through harnessing to the three Government Furnished ECUs located in the DM. The ECUs in turn are connected via harnessing to the HST486 1553 interface connector (J9) located in HST Bay 1. The Government Furnished ECUs will be modified to provide redundant 1553 compatible outputs. See Figure 3-1.

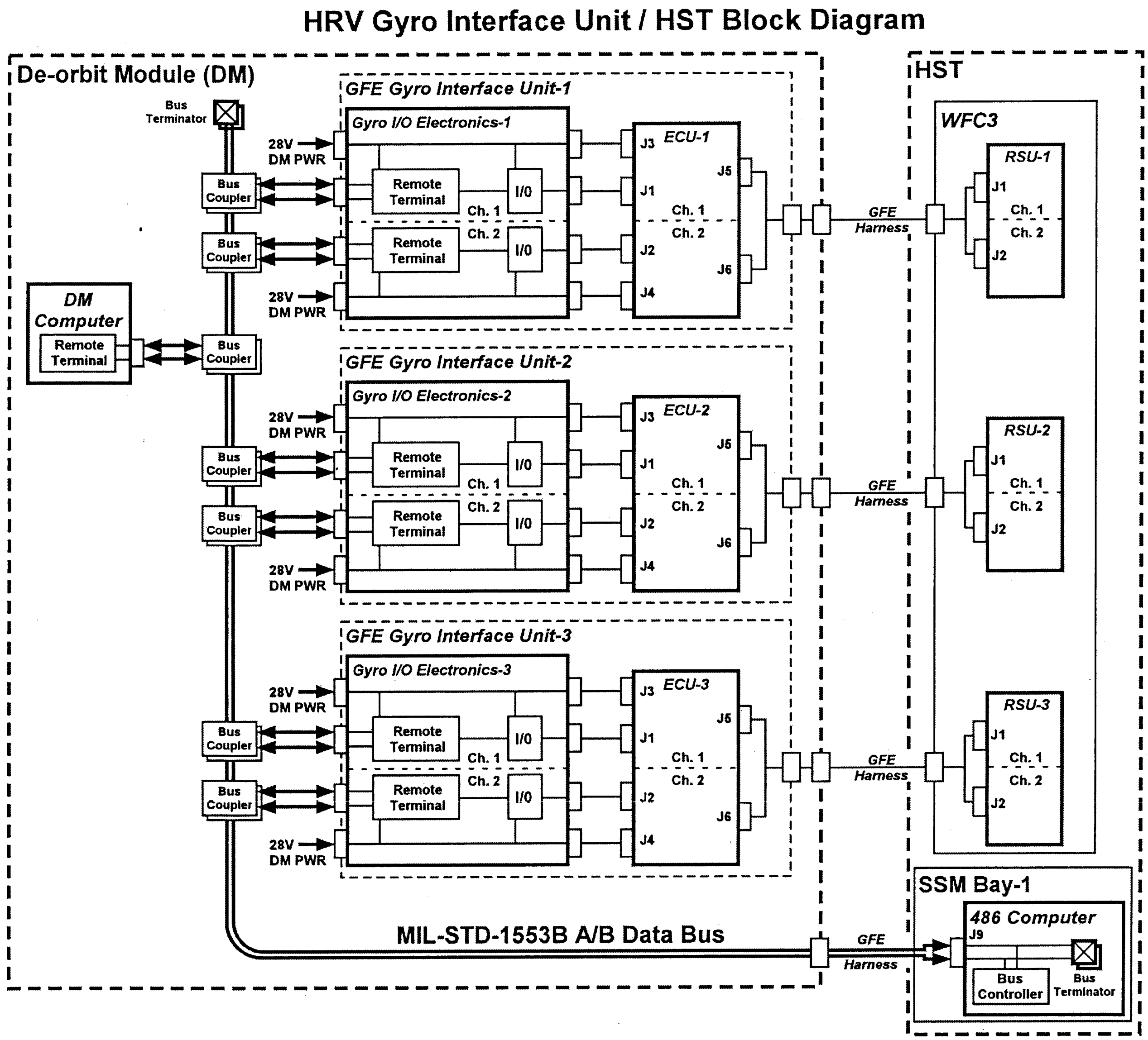


Figure 3-1 HRV/HST Gyro Interface Block

The augmentation of the HST batteries with HRV batteries, residing in the DM (see Figure 3-2), is accomplished by connecting two HST Solar Array 3 (SA3) redundant power feeds located at each of the HST DBA2s to the HRV batteries. This allows the HRV batteries to be charged by the SA3s. The HRV mates to the HST AB J101 umbilical and feeds either SA3 power or HRV battery power in parallel to the HST bus.

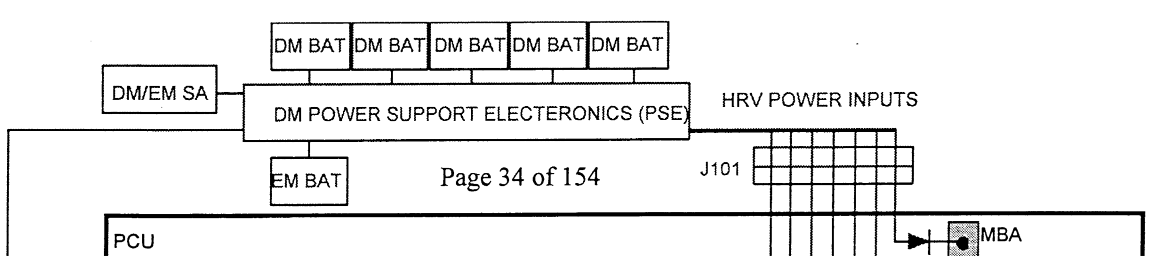


Figure 3-2 HRV Battery Augmentation
(P105 and P106 and NCS power feeds not shown.)

The exchange of COSTAR with COS in axial instrument Bay 4 is accomplished by opening the aft shroud –V2 doors, reconfiguring the COSTAR Y-harness, removing COSTAR, then inserting COS and closing the doors.

At the completion of the Hubble Robotic Servicing and De-orbit Mission (HRSDM) servicing phase, the grapple arm stows the robot and itself. The DM commands the separation of the EM. The DM remains attached to HST for battery/gyro augmentation and performs the controlled re-entry at end-of-mission. The EM de-orbits in accordance with NPD 8710.3.

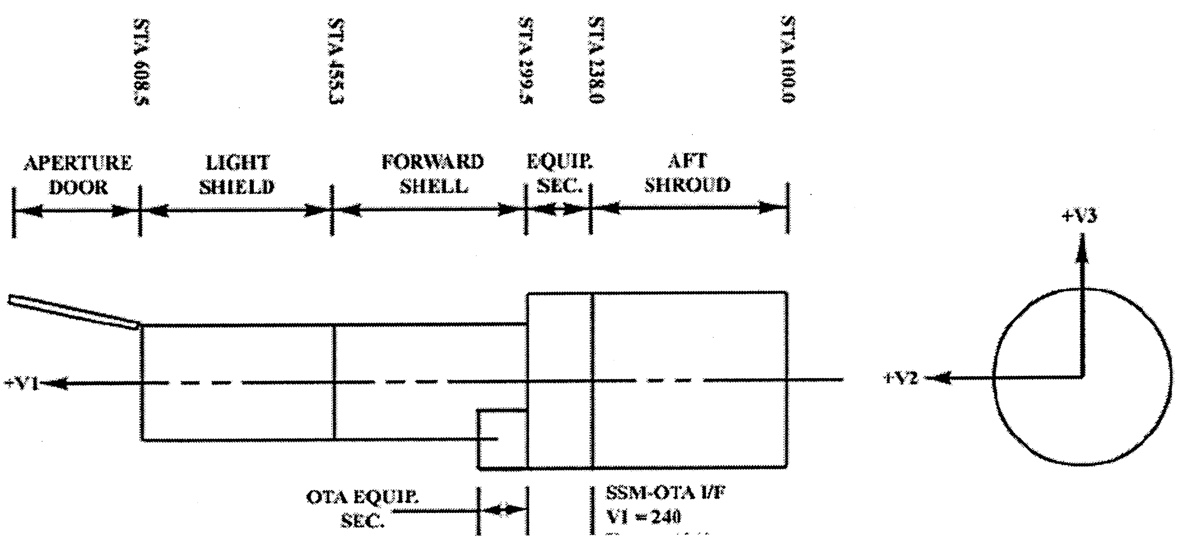
3.1.1 Launch Vehicle (LV)

The HRV shall be launched on an ELV that is provided through the NASA Launch Services (NLS) contract.

The HRV separation system shall be provided by the LV. The relative separation velocity and tipoff constraint requirements are contained in the HRV to LV Interface Requirements Document (IRD).

3.1.2 Coordinate Systems

The HST coordinate system, shown in Figure 3-3, is a right-handed, orthogonal coordinate system with the $+V_1$ (optical) axis on the HST centerline extending along the long axis of the HST out the aperture door. The origin is 100 inches behind the Surface of the AB. The $+V_3$ axis (Sun direction) extends perpendicular to the SA mast and parallel to the HST keel fitting. The $+V_2$ axis extends parallel to the SA mast to complete the right-handed coordinate system.



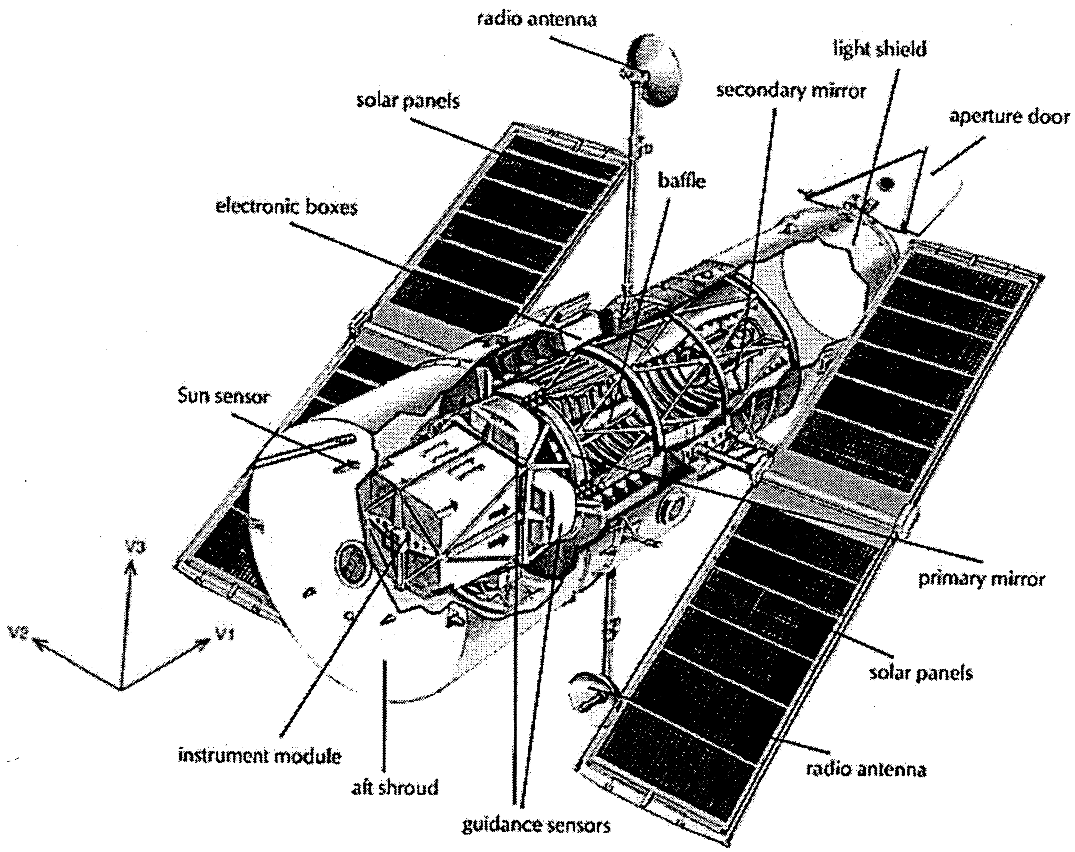


Figure 3-3 HST Coordinate System

3.1.2.1 HRV Coordinate System

The HRV coordinate system shall be a right-hand, mutually orthogonal coordinate system (H1,H2,H3) with the origin offset 400 inches in the -V1 direction from the aft bulkhead (100 V1,V2,V3), and the H2 and H3 axis shall align with the HST V2 and V3 axis respectively. See Figure 3-4.

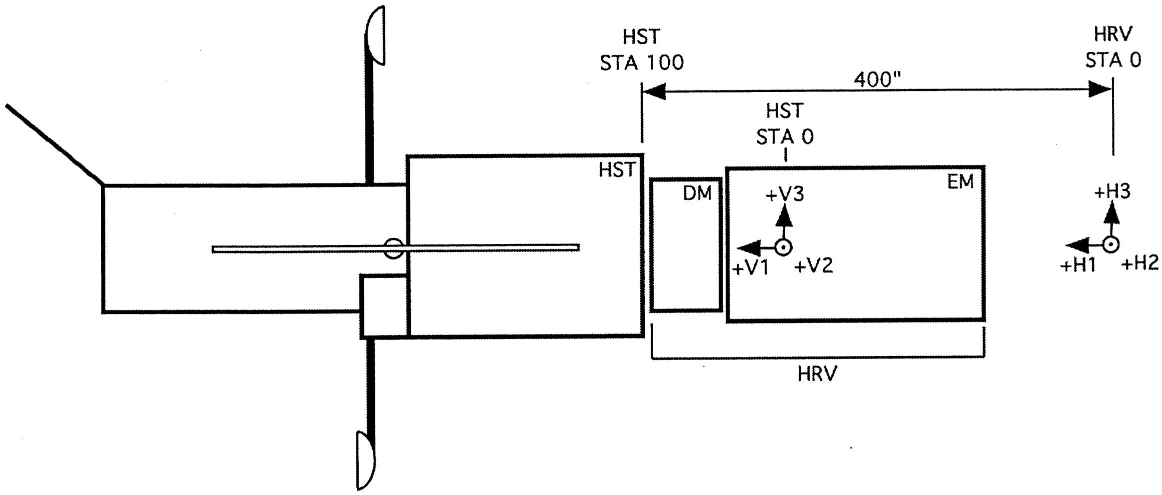


Figure 3-4 HRV Coordinate System

3.1.3 Tolerances

Unless otherwise noted, all dimensions are in inches and tolerances are as follows:

Linear Dimensions
- .XXX = ± 0.010
- .XX = ± 0.03
- .X = ± 0.1 Angles = ± 0.5 deg

All dimensions of the above figures are applied at 68°F.

3.2 PERFORMANCE (Note: Level II Requirements Section)

3.2.1 Autonomous Pursuit and Capture

The HRV shall be capable of pursuit, proximity operations, and capture with the HST in an un-powered state at a maximum altitude 560 km and an orbital inclination of 28.45 degrees.

3.2.1.1 Uncontrolled HST Body Rate

The HRV shall meet Section 3.2.1 with HST body rates of up to 0.22 degrees per second per axis. (**TBR**)

3.2.1.1.1 Controlled HST Body Rate

The controlled HST body rates shall be less than or equal to V1=0.057 deg/sec, V2 ≤ 0.046 deg/sec, V3 ≤ 0.132 deg/sec except at orbit dawn when maximum body rates are estimated to be V1 ≤ 0.138 deg/sec, V2 ≤ 0.103 deg/sec, and V3 ≤ 0.132 deg/sec.

3.2.1.2 Capture and Docking Attempts

The HRV shall be capable of a minimum of four capture/docking attempts.

3.2.1.3 Video Observation

The HRV shall provide real time video transmission of proximity operations, and capture with HST. Resolution and frame rate shall support ground supervision of critical operations as specified in the Grapple Arm ICD, Section 3.2.1.2.3(e).

3.2.1.4 Range Rate Redundancy

The HRV shall redundantly acquire range, range rate, and orientation data (relative to the HST) data using two different types of sensors systems during the proximity operations and capture mission phases.

3.2.1.5 Ground Abort Contingency

The HRV shall provide contingency ground abort capability for all autonomous operations.

3.2.1.6 Rendezvous Lifetime

The HRV shall provide pursuit, proximity operations, capture and servicing capability for a minimum of one year after launch and successful orbit insertion.

3.2.2 HST De-orbit

The HRV shall provide the means to perform a controlled re-entry of HST consistent with NPD 8710.3.

3.2.2.1 De-orbit Module (DM) Autonomy

The ability of the DM to de-orbit the HST shall be independent of the health or configuration of the HST.

3.2.2.2 De-orbit Lifetime

The HRV shall be capable of de-orbit operations at anytime after servicing up to a minimum of seven years from launch.

3.2.3 HST Servicing

3.2.3.1 Telerobotic Servicing

Servicing shall include telerobotic capability. For the purpose of this document, "telerobotic" is defined as in-orbit robotic operations controlled from a ground based command center.

3.2.3.2 Servicing Video Observation

The HRV shall provide real time video transmission during all servicing operations. Resolution and frame rate shall support ground supervision of critical operations (**TBD**).

3.2.3.3 Battery Augmentation

The HRV shall provide a means to augment HST batteries as specified in Section 3.3.4.2.

3.2.3.4 WFC3 Change-out/RSU Augmentation

The HRV shall provide the means to exchange WF/PC II with WFC3 containing 3 RSUs.

3.2.3.5 COSTAR/COS Change-out

The HRV shall provide the means to exchange COSTAR with COS.

3.2.4 HST Attached Science Operations

After servicing HST, the combined HST/HRV shall meet Level I requirements in STR-78 and Level II pointing stability requirements as found in STR-125 Section 3.1.2.2.

3.2.4.1 HST Power Augmentation

The HRV shall provide an EOL power augmentation load capability (including successful hook up the HST SA3 power source) of 2500 Watts orbital average and up to 105 Amps peak at the HST AB J101 connector or P105/P106 connectors over the operating voltage range specified in Section 3.3.4.7. The HRV power augmentation load capability shall be based upon the SA3 string level performance as defined in Section 3.3.4.1 with 76 operational SA3 strings at a 15 degree SA3 incidence angle. The HST contribution to the shared electrical power system responsibility is defined in Sections 3.3.4.1 and 3.3.4.2.

The combined losses associated with the HST SA3 power tap, J101 umbilical harness, and any power conversion device, if used, may reduce the effective SA3 power available to HST to less than what is required to meet the aphelion HST science operating load at EOL. The DM solar array shall supplement the SA3 power source as required to meet the EOL HST power augmentation load requirement.

3.2.4.2 HST Control Authority with HRV

Any appendage of the portion of the HRV that remains attached to the HST during science operations shall have maximum modal gains, K_B, of 0.04 between 0 and 1 hz, and 0.02 greater than 1 hz.

3.2.4.3 HRV Disturbances

Any module of the HRV that remains attached to HST during science operations shall limit the disturbance torques across the HST AB to less then .004 newton meters (0.035 in-lbf).

3.2.4.3.1 HRV to HST Impulse Transients

Any module of the HRV that remains attached to HST during science operations shall limit any Enter Orbit Day (EOD) or Enter Orbit Night (EON) thermal change impulse transients to a maximum angular momentum change of 0.018 newton-meter-second (0.16 in-lbf-sec).

3.2.4.4 HRV Science Mission Life

The HRV support for HST science mission lifetime shall be a minimum of five years from the completion of servicing.

3.3 HST to HRV Interfaces

3.3.1 HST Mechanical

3.3.1.1 HRV Coordinate System

The HRV coordinate system shall be as defined in Section 3.1.2.

3.3.1.2 Capture and Docking

3.3.1.2.1 Primary Capture

The HRV shall provide a primary capture mode using one of the two HST grapple fixtures, located at HST station 358 (V1, 258 inches forward of the Aft Bulkhead) and ±46 inches (V2) (Reference Lockheed drawings 4177659, 4171580, 4171583 and 4177051).

3.3.1.2.2 Docking and Alternative Capture

The HRV shall dock to and provide the capability to alternatively capture the HST at the HST AB FSS Berthing Pins, see Figure 3-5.
The HST has three equidistant FSS Berthing Pins located on the HST AB at HST station 93.970 inches (V1) and at a radius in the V2 – V3 plane of 36.000 inches) (Reference Lockheed drawings 4177659, 4175792 and 4171550). One of the three equidistant FSS Berthing Pins is aligned with the +V3 axis. An interface verification tool (GFE) will be supplied for FSS Berthing Pin and J101 interface verification, 96337201000 (FSS Interface Gauge Assy.).

HRV latch-to-latch co-planarity shall be less than or equal to 0.015 inches.

The AB has a berthing target that is shown in Figure 3-5, reference Lockheed drawing 4175650.

3.3.1.2.3 Backup Capture Mode

The backup capture mode shall use either one of the station 240 two trunnion fittings located on the +/-V2 sides of HST, or the station 240 keel fitting on +V3.

3.3.1.2.4 HRV Arm Docking Position

The HRV arm shall be located at the AB 120 deg position.

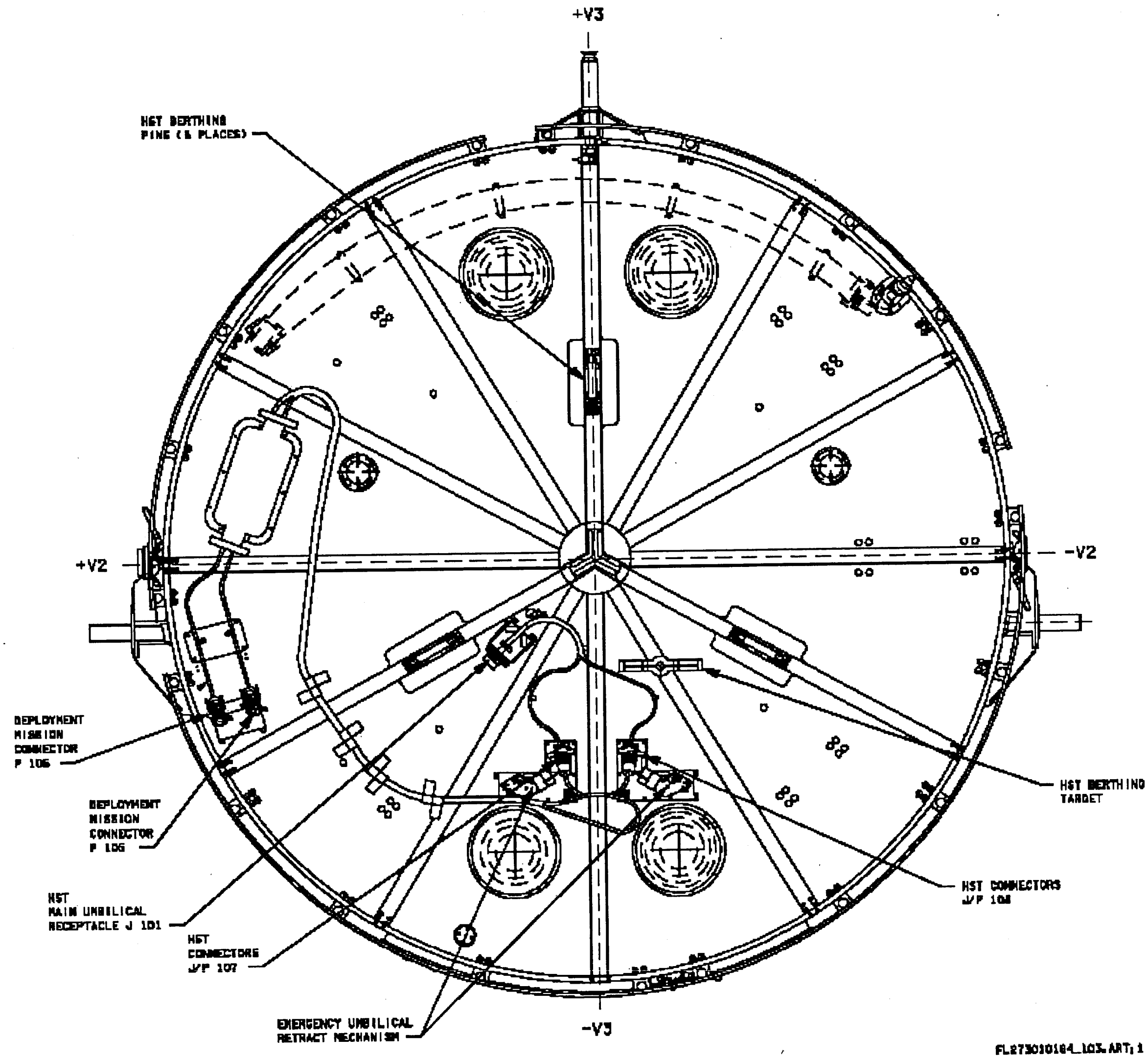


Figure 3-5 HST Aft Bulkhead Layout

(Except Cooling System conduit)

3.3.1.3 Clearances

3.3.1.3.1 Grapple Clearances

The HST static envelope is defined in Section 3.3.1.16.1. The SA3 and High Gain Antenna (HGA) sweep volumes are shown in Figure 3-6. This figure protects for GA dynamics of an additional 6 inches.

3.3.1.3.1.1 Grapple Fixture Capture Tolerances

To grapple using the Grapple Arm End Effector to a Grapple Fixture requires the following alignment and positioning requirements, as shown in Figure 3-7:

± 15 deg about two axes (pitch and yaw)
± 10 deg in roll
4 inch band in axial direction
4 inch band in radial directions

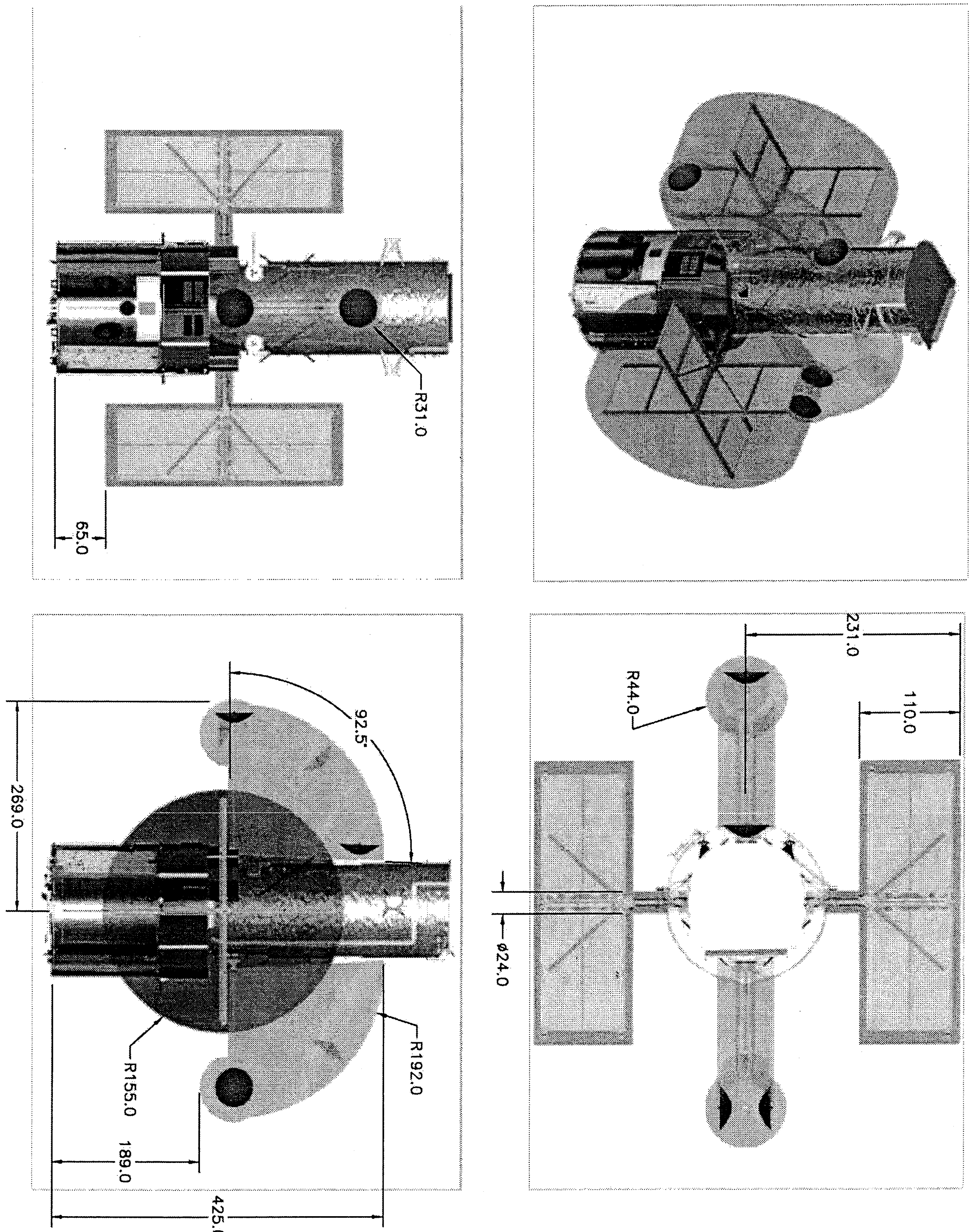


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Figure 3-6 HST SA3 and HGA Sweep Volumes (TBD)

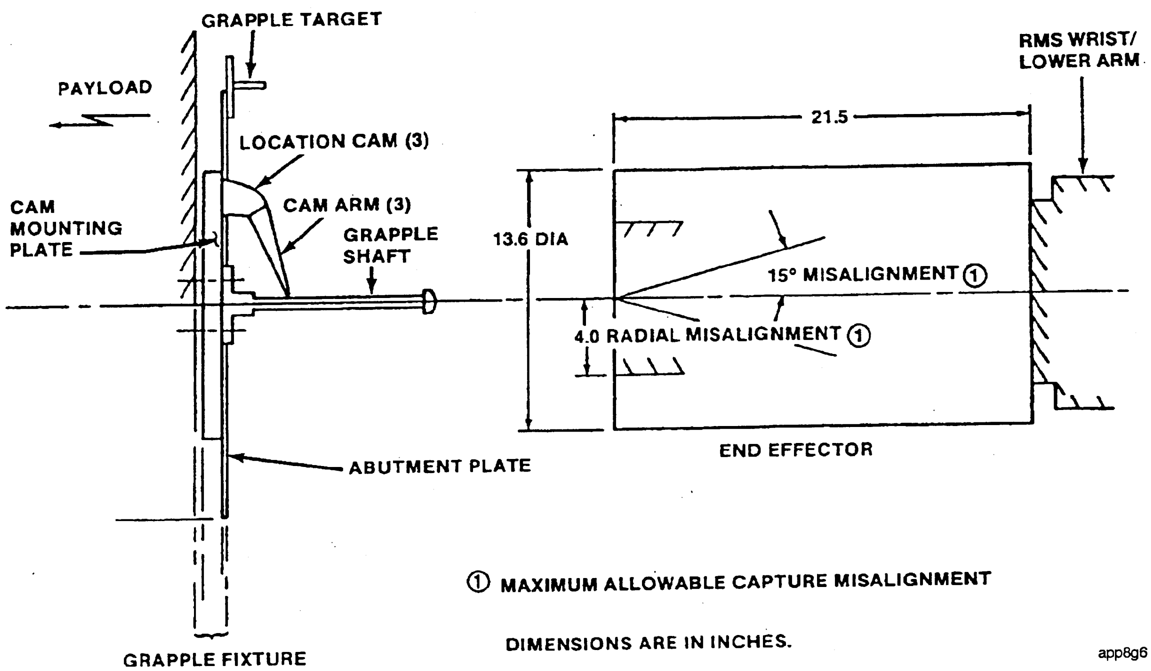


Figure 3-7 Grapple Fixture Capture Tolerances

3.3.1.3.2 Docked Clearances

The HRV shall maintain at least a one-inch static clearance between the HST and HRV (except at structural load paths). The HST AB static envelope is defined in Lockheed drawing 4171550 and GSFC drawing GE 2044728.

3.3.1.3.3 Electrical Connector Clearances

The DM design shall provide (TBD) inches of clearance to the P105 and P106 connectors for contingency umbilical mate by robotic means, reference Lockheed drawing 4171590, Sheet 1 (P/N 4171599-501). Tables 3-1 and 3-2 define the pin outs for these connectors.

Table 3-1 Umbilical Pin outs for P105

Pin	Signal Description	Pin	Signal Description
A	EXT MAIN A1 PWR RTN	**P**	EXT MAIN A2 PWR RTN
B	EXT MAIN A1 PWR	**R**	EXT MAIN A2 PWR
C	EXT ESS A PWR	**S**	EXT MAIN A3 PWR RTN
D	EXT MAIN A1 PWR RTN	**T**	EXT MAIN A3 PWR
E	EXT MAIN A1 PWR	**U**	INT ESS ON MONITOR(UMB)
F	RSU SURV HTR CH 1 PWR(UMB)*	**V**	INT MAIN OFF CONTROL(UMB)
G	INT ESS ON CONTROL(UMB)	**W**	INT MAIN ON CONTROL(UMB)
H	INT ESS OFF CONTROL(UMB)	**X**	EXT MAIN A3 PWR RTN
J	EXT MAIN ON CONTROL(ACP)	**Y**	EXT MAIN A3 PWR
K	EXT MAIN OFF CONTROL(ACP)	**Z**	SI WORK LTS PWR 2*
L	EXT MAIN A2 PWR RTN	**A**	SI WORK LTS PWR 3 (SPARE)*
M	EXT MAIN A2 PWR		
N	SI WORK LTS PWR I(UMB)		

* This function shall not be provided by the HRV.

Table 3-2 Umbilical Pin outs for P106

Pin	Signal Description	Pin	Signal Description
A	EXT MAIN B1 PWR RTN	P	EXT MAIN B2 PWR RTN
B	EXT MAIN B1 PWR	R	EXT MAIN B2 PWR
C	EXT ESS B PWR	S	EXT MAIN B3 PWR RTN
D	EXT MAIN B1 PWR RTN	T	EXT MAIN B3 PWR
E	EXT MAIN B1 PWR	U	EXT ESS ON MONITOR(UMB)
G	INT ESS ON CONTROL(UMB)	V	EXT MAIN PWR ON MON(UMB)
H	INT ESS OFF CONTROL(UMB)	W	INT ESS ON MONITOR(UMB)
J	EXT ESS ON CONTROL(ACP)	X	EXT MAIN B3 PWR RTN
K	EXT ESS OFF CONTROL(ACP)	Y	EXT MAIN B3 PWR
L	EXT MAIN B2 PWR RTN	Z	FHST SHUTTER CLOSE PWR(UMB)*
M	EXT MAIN B2 PWR	A	MAIN BUS ON MONITOR(UMB)
N	RSU SURV HTR CH 2 PWR(UMB)*		

* This function shall not be provided by the HRV.

3.3.1.3.4 Low Gain Antenna (LGA) Clearances

The HST Aft LGA static envelope is defined in drawing 4171550. A minimum of 95% hemispherical coverage shall be provided for Tracking and Data Relay Satellite System (TDRSS) forward link coverage, except for HST hardware safemode (Pointing and Safemode Electronics Assembly (PSEA)) operations. During PSEA operations a 1.7 dB 125 bps received TDRSS forward link service loss in radio frequency (RF) power is allocated to the HRV attached signal attenuations and/or interferences.

3.3.1.3.5 Coarse Sun Sensor (CSS) Clearances

The HST Aft CSS-4 (located on a bracket off of the AB with hemispherical coverage in –V1 with respect to the V2/V3 plane) static envelope is defined in Lockheed drawing 4171590. The HST Aft CSS-5 (located on the same bracket as CSS-4 on a 45 degree angle in the –V1/-V3 plane) static envelope is defined in Lockheed drawing 4171590.

The HST Aft CSS-3 (located on a 90 degree bracket off of the AB with hemispherical coverage in +V3 with respect to the V1/V2 plane) static envelope is defined in Lockheed drawing 4171590.

The clearances associated with these units are defined in Section 3.3.1.17.1.1, CSS Optical Field of View (FOV).

3.3.1.4 SA3 Mechanical Interface for Power Input

Two (J6A) of the four SA3 power connectors shall be G&H Industries BL02F25-61-PA-935 and the other two (J8A) shall be G&H Industries BL02F25-61-PC-935. Tables 3-3 and 3-4 define the pin outs for these connectors.

Table 3-3 SA3 P6A Connector Pin Functions

Pin	Function	Pin	Function	Pin	Function
A	A STRING 1 -	Y	CC STRING 30+	V	DD STRING 34+
B	A STRING 2 -	Z	NOT USED	W	K/A ENBL[1]
C	A STRING 2 +	A	DD STRING 33-	w	K/A ENBL[1]
D	B STRING 5 -	B	DD STRING 34-	X	K/A PWR RTN[1]
E	B STRING 6 -	C	A STRING 1 +	X	K/A ENBL RTN[1]
F	C STRING 9 -	D	NOT USED	Y	AMD[1]
G	C STRING 9 +	E	B STRING 5 +	Z	AMD RTN[1]
H	C STRING 10 -	F	B STRING 6 +	AA	NOT USED
J	D STRING 13 -	G	NOT USED	BB	NOT USED
K	D STRING 14 -	H	C STRING 10 +	CC	NOT USED
L	D STRING 14 +	I	D STRING 13+	DD	NOT USED
M	E STRING 17 -	J	NOT USED	EE	NOT USED
N	E STRING 18 +	K	E STRING 17 +	FF	NOT USED
P	E STRING 18 -	M	NOT USED	GG	NOT USED
R	AA STRING 21-	N	AA STRING 21+	HH	NOT USED
S	AA STRING 22-	P	AA STRING 22+	JJ	NOT USED
T	BB STRING 25+	Q	NOT USED	KK	NOT USED
U	BB STRING 25-	R	BB STRING 26+	LL	D STRING 37+
V	BB STRING 26-	S	CC STRING 29+	MM	D STRING 37 -
W	CC STRING 29-	T	NOT USED	NN	E STRING 38 -
X	CC STRING 30-	U	DD STRING 33+	PP	E STRING 38 +

Note: 1) Not required for HRV

Table 3-4 SA3 P8A Connector Pin Functions

Pin	Function	Pin	Function	Pin	Function
A	A STRING 3 -	Y	CC STRING 32+	V	DD STRING 36+
B	A STRING 4 -	Z	NOT USED	W	K/A ENBL[1]
C	A STRING 4 +	A	DD STRING 35-	W	K/A ENBL[1]
D	B STRING 7 -	B	DD STRING 36-	X	K/A PWR RTN[1]
E	B STRING 8 -	C	A STRING 3 +	X	K/A ENBL RTN[1]
F	C STRING 11-	D	NOT USED	Y	AMD[1]
G	C STRING 11+	E	B STRING 7 +	Z	AMD RTN[1]
H	C STRING 12-	F	B STRING 8 +	AA	NOT USED
J	D STRING 15-	G	NOT USED	BB	NOT USED
K	D STRING 16-	H	C STRING 12 +	CC	NOT USED
L	D STRING 16+	I	D STRING 15+	DD	NOT USED
M	E STRING 19-	J	NOT USED	EE	NOT USED
N	E STRING 20+	K	E STRING 19 +	FF	NOT USED
P	E STRING 20-	M	NOT USED	GG	NOT USED
R	AA STRING 23-	N	AA STRING 23+	HH	NOT USED
S	AA STRING 24-	P	AA STRING 24+	JJ	NOT USED
T	BB STRING 27+	Q	NOT USED	KK	NOT USED
U	BB STRING 27-	R	BB STRING 28+	LL	D STRING 39+
V	BB STRING 28-	S	CC STRING 31+	MM	D STRING 39-
W	CC STRING 31-	T	NOT USED	NN	E STRING 40-
X	CC STRING 32-	U	DD STRING 35+	PP	E STRING 40+

Note: 1) Not required for HRV

3.3.1.5 P101 Mechanical Interface to Provide Power

The main mechanical umbilical actuator (P101) will be provided as GFE, see Figure 3-8. The mechanical interfaces are defined in Lockheed drawing 4175788. The HRV shall meet the pin outs of J101 as defined in Table 3-5.

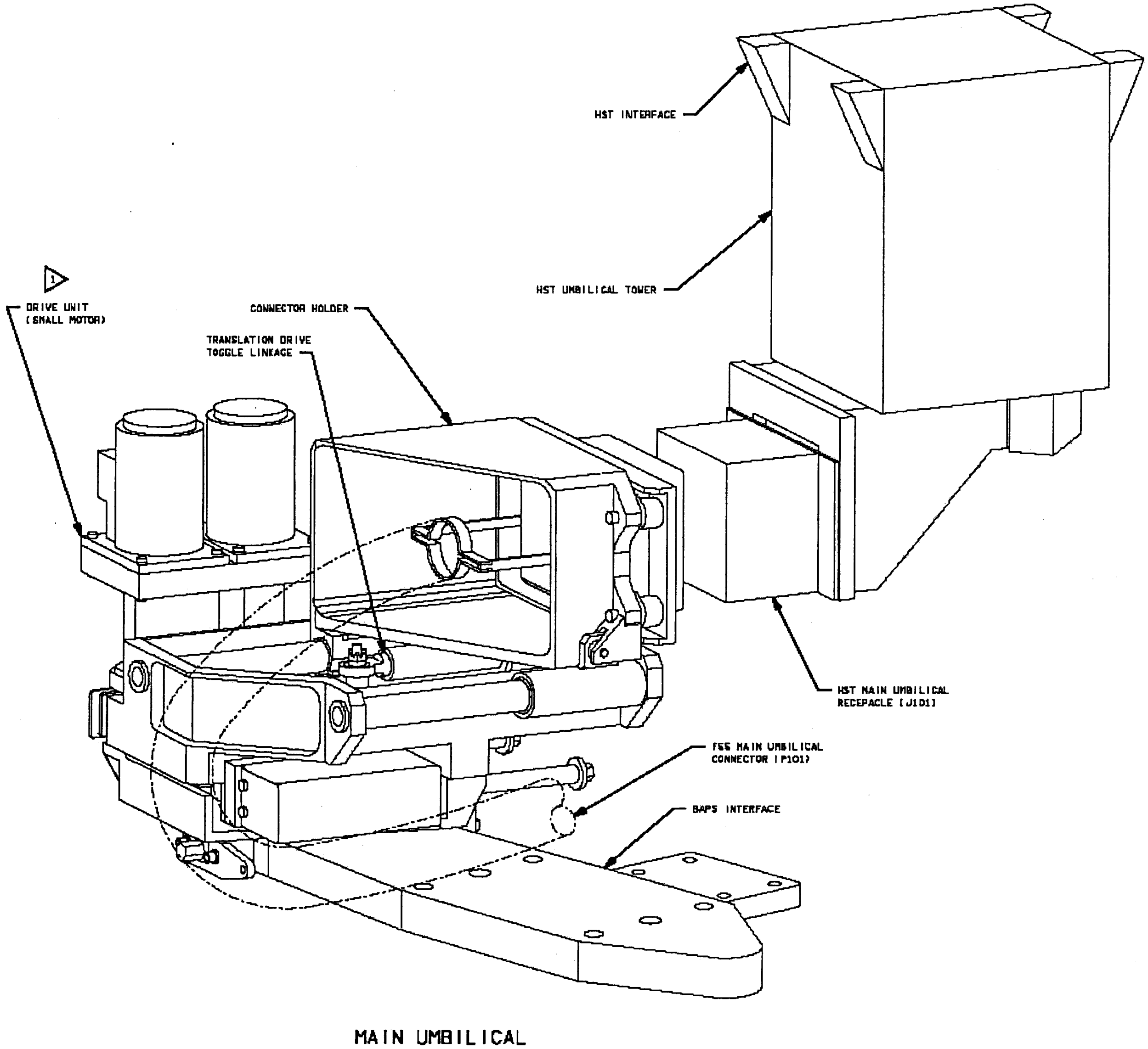


Figure 3-8 Main (P101) Umbilical Actuator

Table 3-5 Umbilical Actuator Pin outs for P101

Pin	Signal Description	Pin	Signal Description
21	HST STRUCTURE GROUND	59	EXT MAIN B2 POWER RETURN
22	EXT MAIN A1 POWER RTN	61	INT ESSENTIAL ON CONTROL
23	EXTERNAL MAIN A1 POWER	62	INT ESS OFF CONTROL
24	EXTERNAL MAIN B3 POWER	66	EXT MAIN A2 POWER RTN
25	EXTERNAL MAIN B3 POWER	68	EXT ESSENTIAL ON CONTROL
26	EXT MAIN B3 POWER RETURN	69	EXT ESS OFF CONTROL
30	INT ESSENTIAL ON CONTROL	71	RSU SURV HTR CH1 POWER
31	INT ESS OFF CONTROL	72	FORWARD SI WORK LIGHTS POWER
33	EXTERNAL ESSENTIAL B POWER	73	EXTERNAL MAIN A2 POWER
34	RSU SURV HTR CH2 POWER	74	EXT MAIN A3 POWER RTN
36	EXTERNAL MAIN ON CONTROL	75	EXT MAIN B1 POWER RETURN
37	EXIERNAL MAIN OFF CONTROL	76	EXTERNAL MAIN B1 POWER
39	EXTERNAL MAIN A1 POWER	78	EXTERNAL MAIN ON MONITOR
40	EXT MAIN A1 POWER RTN	79	EXT ESSENTIAL ON MONITOR
41	EXT MAIN A1 POWER RETURN	81	EXTERNAL ESSENTIAL A POWER
42	EXTERNAL MAIN B2 POWER	82	AFT SI WORK LIGHTS POWER
43	FHST SHUTTER CLOSE POWER	84	INT ESSENTTAL ON MONITOR
46	INTERNAL MAIN ON CONTROL	85	INTERNAL MAIN ON MONITOR
47	INTERNAL MAIN OFF CONTROL	89	EXT MAIN A3 POWER RTN
49	EXT MAIN B2 POWER RETURN	90	EXTERNAL MAIN A3 POWER
54	INT ESSENTIAL ON MONITOR	91	EXTERNAL MAIN A3 POWER
56	EXT MAIN A2 POWER RTN	92	EXTERNAL MAIN B1 POWER
57	EXTERNAL MAIN A2 POWER	93	EXT MAIN B1 POWER RETURN
58	EXTERNAL MAIN B2 POWER	94	HST STRUCTURE GROUND

3.3.1.5.1 Main (J101) Umbilical Actuator Envelope

The Main (J101) Umbilical Actuator envelope is 11 x 7 14 inches (H x W x L).

3.3.1.5.2 Main (J101) Umbilical Actuator Weight

The Main (J101) Umbilical Actuator weight is 26 lbs. (TBD).

3.3.1.6 Gyro Interface Unit (GIU) Mechanical Interface

The three GIUs shall be housed in the DM and will be provided as GFE. GIU mechanical interfaces shall be as defined in drawing (**TBD**). This drawing identifies the interface connectors.

3.3.1.6.1 GIU Mechanical Envelope

The GIU envelope is: 14.0 x 9.0 x 19.0 inches (H x W x L) (TBR).

3.3.1.6.2 GIU Weight

The GIU weight is 25 lbs. (TBR).

3.3.1.6.3 GIU (ECU-to-RSU) Pin Outs

The GIU ECU connectors J5 and J6 ultimately connect to the respective J1 and J2 of the paired RSU. The pin outs for the ECU J5 and J6, and RSU J1 and J2 are provided in Tables 3-6 through 3-11. The intermediate in-line interfaces between the ECU and RSU are TBD. The pin outs for the ECU power connectors J3 and J4 are provided in Tables 3-12 through 3-14.

3.3.1.6.4 GIU Wire size

Each GIU circuit shall have a minimum wire gauge size of 20 (**TBR**).

Table 3-6 ECU-1 to RSU-1 Channel-1 Connector Pin Functions

Description	ECU1 P5 Pin #	GIU1 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P1 Pin #	Description
RSU 1 1 -15 VDC	1	TBD	TBD	TBD	37	RSU 1 1 -15 VDC
RSU 1 1 -15 VDC RTN	2	TBD	TBD	TBD	38	RSU 1 1 -15 VDC RTN
RSU 1 1 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	RSU 1 1 SIM TORQ SIG LO
RGA 1 1 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 1 1 SHIELD CARRY THRU(47,46)
RSU 1 1 PWM HI	5	TBD	TBD	TBD	30	RSU 1 1 PWM HI
RSU 1 1 +15 VDC	6	TBD	TBD	TBD	27	RSU 1 1 +15 VDC
RSU 1 1 +15 VDC RTN	7	TBD	TBD	TBD	28	RSU 1 1 +15 VDC RTN
RSU 1 1 +20 VDC RTN	8	TBD	TBD	TBD	36	RSU 1 1 +20 VDC RTN
RSU 1 1 +5 VDC RTN	9	TBD	TBD	TBD	45	RSU 1 1 +5 VDC RTN
RSU 1 1 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	RSU 1 1 SIM TORQ SIG HI
RSU 1 1 MODE CMD	11	TBD	TBD	TBD	54	RSU 1 1 MODE CMD
RSU 1 1 307.2 KHZ HI	12	TBD	TBD	TBD	48	RSU 1 1 307.2 KHZ HI
RGA 1 1 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 1 1 SHIELD GND(48,49)
RSU 1 1 PWM LO	14	TBD	TBD	TBD	31	RSU 1 1 PWM LO
RSU 1 1 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	RSU 1 1 9.6 KHZ REF LO
RSU 1 1 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	RSU 1 1 9.6 KHZ REF HI
RGA 1 1 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 1 1 SHIELD GND(20,19)
RSU 1 1 +20 VDC	20	TBD	TBD	TBD	26	RSU 1 1 +20 VDC
RGA 1 1 SHIELD GND(39,40)	21	TBD	TBD	TBD	35	RGA 1 1 SHIELD GND(34,43)
RSU 1 TEMP SENSOR LO	22	TBD	TBD	TBD	51	RSU 1 TEMP SENSOR

Description	ECU1 P5 Pin #	GIU1 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P1 Pin #	Description
						LO
RSU 1 1 +5 VDC	23	TBD	TBD	TBD	52	RSU 1 1 +5 VDC
RSU 1 1 SIM TORQ ENBL	24	TBD	TBD	TBD	53	RSU 1 1 SIM TORQ ENBL
RGA 1 1 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 1 1 SHIELD GND(54,43)
RGA 1 1 SHIELD GND(22,41)	26	TBD	TBD	TBD	61	RGA 1 1 SHIELD GND(22,41)
RSU 1 1 307.2 KHZ LO	27	TBD	TBD	TBD	49	RSU 1 1 307.2 KHZ LO
RGA 1 1 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 1 1 SHIELD GND(50,42)
RGA 1 1 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 1 1 SHIELD GND(30,31)
RSU 1 1 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	RSU 1 1 WHL DRIVE PHASE B HI
RGA 1 1 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 1 1 SHIELD GND(14,13)
RSU 1 1 SYNC LO	32	TBD	TBD	TBD	14	RSU 1 1 SYNC LO
RSU 1 1 SYNC HI	33	TBD	TBD	TBD	13	RSU 1 1 SYNC HI
RGA 1 1 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	RGA 1 1 CONTROL SENSOR LO
RGA 1 1 CONTROL SENSOR HI	37	TBD	TBD	TBD	17	RGA 1 1 CONTROL SENSOR HI
RGA 1 1 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 1 1 SHIELD GND(18,17)
RSU 1 1 RATE IN HI	39	TBD	TBD	TBD	34	RSU 1 1 RATE IN HI
RSU 1 1 RATE IN LO	40	TBD	TBD	TBD	43	RSU 1 1 RATE IN LO
RSU 1 TEMP SENSOR HI	41	TBD	TBD	TBD	44	RSU 1 TEMP SENSOR HI
RGA 1 1 SHIELD	42	TBD	TBD	TBD	64	RGA 1 1 SHIELD

Description	ECU1 P5 Pin #	GIU1 Departur e I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P1 Pin #	Description
GND(43,44)						GND(65,66)
RSU 1 1 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	RSU 1 1 GYRO TMP MON SENS HI
RSU 1 1 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	RSU 1 1 GYRO TMP MON SENS LO
RGA 1 1 SURV HEATER MON	45	TBD	TBD	TBD	62	RGA 1 1 SURV HEATER MON
RGA 1 1 SURV HEATER +28V	46	TBD	TBD	TBD	57	RGA 1 1 SURV HEATER +28V
RGA 1 1 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	RGA 1 1 SURV HEATER +28V RTN
RGA 1 1 NORM HEATER HI	48	TBD	TBD	TBD	50	RGA 1 1 NORM HEATER HI
RGA 1 1 NORM HEATER LO	49	TBD	TBD	TBD	42	RGA 1 1 NORM HEATER LO
RSU 1 1 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	RSU 1 1 WHL DRIVE PHASE B LO
RGA 1 1 SHIELD GND(30,51)	52	TBD	TBD	TBD	16	RGA 1 1 SHIELD GND(23,24)
RSU 1 1 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	RSU 1 1 WHL DRIVE PHASE A LO
RSU 1 1 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	RSU 1 1 WHL DRIVE PHASE A HI
RGA 1 1 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 1 1 SHIELD GND(9,8)
RGA 1 1 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 1 1 SHIELD GND(1,5)
RSU 1 1 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	RSU 1 1 SUSP EXCIT RTN
RSU 1 1 SUSP EXCIT	58	TBD	TBD	TBD	5	RSU 1 1 SUSP EXCIT

Description	ECU1 P5 Pin #	GIU1 Departur e I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P1 Pin #	Description
RGA 1 1 CONT THERM LO	59	TBD	TBD	TBD	4	RGA 1 1 CONT THERM LO
RGA 1 1 CONT THERM HI	60	TBD	TBD	TBD	10	RGA 1 1 CONT THERM HI
RGA 1 1 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 1 1 SHIELD GND(4,10)

Table 3-7 ECU-1 to RSU-1 Channel-2 Connector Pin Functions

Description	ECU1 P6 Pin #	GIU1 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P2 Pin #	Description
RSU 1 2 -15 VDC	1	TBD	TBD	TBD	37	RSU 1 2 -15 VDC
RSU 1 2 -15 VDC RTN	2	TBD	TBD	TBD	38	RSU 1 2 -15 VDC RTN
RSU 1 2 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	RSU 1 2 SIM TORQ SIG LO
RGA 1 2 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 1 2 SHIELD CARRY THRU(47,46)
RSU 1 2 PWM HI	5	TBD	TBD	TBD	30	RSU 1 2 PWM HI
RSU 1 2 +15 VDC	6	TBD	TBD	TBD	27	RSU 1 2 +15 VDC
RSU 1 2 +15 VDC RTN	7	TBD	TBD	TBD	28	RSU 1 2 +15 VDC RTN
RSU 1 2 +20 VDC RTN	8	TBD	TBD	TBD	36	RSU 1 2 +20 VDC RTN
RSU 1 2 +5 VDC RTN	9	TBD	TBD	TBD	45	RSU 1 2 +5 VDC RTN
RSU 1 2 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	RSU 1 2 SIM TORQ SIG HI
RSU 1 2 MODE CMD	11	TBD	TBD	TBD	54	RSU 1 2 MODE CMD
RSU 1 2 307.2 KHZ HI	12	TBD	TBD	TBD	48	RSU 1 2 307.2 KHZ HI
RGA 1 2 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 1 2 SHIELD GND(48,49)
RSU 1 2 PWM LO	14	TBD	TBD	TBD	31	RSU 1 2 PWM LO
RSU 1 2 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	RSU 1 2 9.6 KHZ REF LO
RSU 1 2 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	RSU 1 2 9.6 KHZ REF HI
RGA 1 2 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 1 2 SHIELD GND(20,19)
RSU 1 2 +20 VDC	20	TBD	TBD	TBD	26	RSU 1 2 +20 VDC
RGA 1 2 SHIELD GND(39,40)	21	TBD	TBD	TBD	35	RGA 1 2 SHIELD GND(34,43)
RSU 1 2 +5 VDC	23	TBD	TBD	TBD	52	RSU 1 2 +5 VDC

Description	ECU1 P6 Pin #	GIU1 Departur e I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P2 Pin #	Description
RSU 1 2 SIM TORQ ENBL	24	TBD	TBD	TBD	53	RSU 1 2 SIM TORQ ENBL
RGA 1 2 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 1 2 SHIELD GND(54,43)
RSU 1 2 307.2 KHZ LO	27	TBD	TBD	TBD	49	RSU 1 2 307.2 KHZ LO
RGA 1 2 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 1 2 SHIELD GND(50,42)
RGA 1 2 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 1 2 SHIELD GND(30,31)
RSU 1 2 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	RSU 1 2 WHL DRIVE PHASE B HI
RGA 1 2 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 1 2 SHIELD GND(14,13)
RSU 1 2 SYNC LO	32	TBD	TBD	TBD	14	RSU 1 2 SYNC LO
RSU 1 2 SYNC HI	33	TBD	TBD	TBD	13	RSU 1 2 SYNC HI
RGA 1 2 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	RGA 1 2 CONTROL SENSOR LO
RGA 1 2 CONTROL SENSOR HI	37	TBD	TBD	TBD	17	RGA 1 2 CONTROL SENSOR HI
RGA 1 2 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 1 2 SHIELD GND(18,17)
RSU 1 2 RATE IN HI	39	TBD	TBD	TBD	34	RSU 1 2 RATE IN HI
RSU 1 2 RATE IN LO	40	TBD	TBD	TBD	43	RSU 1 2 RATE IN LO
RGA 1 2 SHIELD GND(43,44)	42	TBD	TBD	TBD	64	RGA 1 2 SHIELD GND(65,66)
RSU 1 2 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	RSU 1 2 GYRO TMP MON SENS HI
RSU 1 2 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	RSU 1 2 GYRO TMP MON SENS LO
RGA 1 2 SURV HEATER	45	TBD	TBD	TBD	62	RGA 1 2 SURV

Description	ECU1 P6 Pin #	GIU1 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU1 P2 Pin #	Description
MON						HEATER MON
RGA 1 2 SURV HEATER +28V	46	TBD	TBD	TBD	57	RGA 1 2 SURV HEATER +28V
RGA 1 2 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	RGA 1 2 SURV HEATER +28V RTN
RGA 1 2 NORM HEATER HI	48	TBD	TBD	TBD	50	RGA 1 2 NORM HEATER HI
RGA 1 2 NORM HEATER LO	49	TBD	TBD	TBD	42	RGA 1 2 NORM HEATER LO
RSU 1 2 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	RSU 1 2 WHL DRIVE PHASE B LO
RGA 1 2 SHIELD GND(30,51)	52	TBD	TBD	TBD	16	RGA 1 2 SHIELD GND(23,24)
RSU 1 2 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	RSU 1 2 WHL DRIVE PHASE A LO
RSU 1 2 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	RSU 1 2 WHL DRIVE PHASE A HI
RGA 1 2 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 1 2 SHIELD GND(9,8)
RGA 1 2 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 1 2 SHIELD GND(1,5)
RSU 1 2 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	RSU 1 2 SUSP EXCIT RTN
RSU 1 2 SUSP EXCIT	58	TBD	TBD	TBD	5	RSU 1 2 SUSP EXCIT
RGA 1 2 CONT THERM LO	59	TBD	TBD	TBD	4	RGA 1 2 CONT THERM LO
RGA 1 2 CONT THERM HI	60	TBD	TBD	TBD	10	RGA 1 2 CONT THERM HI
RGA 1 2 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 1 2 SHIELD GND(4,10)

Table 3-8 ECU-2 to RSU-2 Channel-1 Connector Pin Functions

Description	ECU2 P5 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P1 Pin #	Description
RSU 2 3 -15 VDC	1	TBD	TBD	TBD	37	RSU 2 3 -15 VDC
RSU 2 3 -15 VDC RTN	2	TBD	TBD	TBD	38	RSU 2 3 -15 VDC RTN
RSU 2 3 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	RSU 2 3 SIM TORQ SIG LO
RGA 2 3 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 2 3 SHIELD CARRY THRU(47,46)
RSU 2 3 PWM HI	5	TBD	TBD	TBD	30	RSU 2 3 PWM HI
RSU 2 3 +15 VDC	6	TBD	TBD	TBD	27	RSU 2 3 +15 VDC
RSU 2 3 +15 VDC RTN	7	TBD	TBD	TBD	28	RSU 2 3 +15 VDC RTN
RSU 2 3 +20 VDC RTN	8	TBD	TBD	TBD	36	RSU 2 3 +20 VDC RTN
RSU 2 3 +5 VDC RTN	9	TBD	TBD	TBD	45	RSU 2 3 +5 VDC RTN
RSU 2 3 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	RSU 2 3 SIM TORQ SIG HI
RSU 2 3 MODE CMD	11	TBD	TBD	TBD	54	RSU 2 3 MODE CMD
RSU 2 3 307.2 KHZ HI	12	TBD	TBD	TBD	48	RSU 2 3 307.2 KHZ HI
RGA 2 3 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 2 3 SHIELD GND(48,49)
RSU 2 3 PWM LO	14	TBD	TBD	TBD	31	RSU 2 3 PWM LO
RSU 2 3 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	RSU 2 3 9.6 KHZ REF LO
RSU 2 3 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	RSU 2 3 9.6 KHZ REF HI
RGA 2 3 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 2 3 SHIELD GND(20,19)
RSU 2 3 +20 VDC	20	TBD	TBD	TBD	26	RSU 2 3 +20 VDC
RGA 2 3 SHIELD	21	TBD	TBD	TBD	35	RGA 2 3 SHIELD

Description	ECU2 P5 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P1 Pin #	Description
GND(39,40)						GND(34,43)
RSU 2 TEMP SENSOR LO	22	TBD	TBD	TBD	51	RSU 2 TEMP SENSOR LO
RSU 2 3 +5 VDC	23	TBD	TBD	TBD	52	RSU 2 3 +5 VDC
RSU 2 3 SIM TORQ ENBL	24	TBD	TBD	TBD	53	RSU 2 3 SIM TORQ ENBL
RGA 2 3 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 2 3 SHIELD GND(54,43)
RGA 2 3 SHIELD GND(22,41)	26	TBD	TBD	TBD	61	RGA 2 3 SHIELD GND(22,41)
RSU 2 3 307.2 KHZ LO	27	TBD	TBD	TBD	49	RSU 2 3 307.2 KHZ LO
RGA 2 3 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 2 3 SHIELD GND(50,42)
RGA 2 3 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 2 3 SHIELD GND(30,31)
RSU 2 3 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	RSU 2 3 WHL DRIVE PHASE B HI
RGA 2 3 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 2 3 SHIELD GND(14,13)
RSU 2 3 SYNC LO	32	TBD	TBD	TBD	14	RSU 2 3 SYNC LO
RSU 2 3 SYNC HI	33	TBD	TBD	TBD	13	RSU 2 3 SYNC HI
RGA 2 3 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	RGA 2 3 CONTROL SENSOR LO
RGA 2 3 CONTROL SENSOR HI	37	TBD	TBD	TBD	17	RGA 2 3 CONTROL SENSOR HI
RGA 2 3 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 2 3 SHIELD GND(18,17)
RSU 2 3 RATE IN HI	39	TBD	TBD	TBD	34	RSU 2 3 RATE IN HI
RSU 2 3 RATE IN LO	40	TBD	TBD	TBD	43	RSU 2 3 RATE IN LO

Description	ECU2 P5 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P1 Pin #	Description
RSU 2 TEMP SENSOR HI	41	TBD	TBD	TBD	44	RSU 2 TEMP SENSOR HI
RGA 2 3 SHIELD GND(43,44)	42	TBD	TBD	TBD	64	RGA 2 3 SHIELD GND(65,66)
RSU 2 3 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	RSU 2 3 GYRO TMP MON SENS HI
RSU 2 3 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	RSU 2 3 GYRO TMP MON SENS LO
RGA 2 3 SURV HEATER MON	45	TBD	TBD	TBD	62	RGA 2 3 SURV HEATER MON
RGA 2 3 SURV HEATER +28V	46	TBD	TBD	TBD	57	RGA 2 3 SURV HEATER +28V
RGA 2 3 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	RGA 2 3 SURV HEATER +28V RTN
RGA 2 3 NORM HEATER HI	48	TBD	TBD	TBD	50	RGA 2 3 NORM HEATER HI
RGA 2 3 NORM HEATER LO	49	TBD	TBD	TBD	42	RGA 2 3 NORM HEATER LO
RSU 2 3 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	RSU 2 3 WHL DRIVE PHASE B LO
RGA 2 3 SHIELD GND(30,51)	52	TBD	TBD	TBD	16	RGA 2 3 SHIELD GND(23,24)
RSU 2 3 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	RSU 2 3 WHL DRIVE PHASE A LO
RSU 2 3 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	RSU 2 3 WHL DRIVE PHASE A HI
RGA 2 3 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 2 3 SHIELD GND(9,8)
RGA 2 3 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 2 3 SHIELD GND(1,5)

Description	ECU2 P5 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P1 Pin #	Description
RSU 2 3 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	RSU 2 3 SUSP EXCIT RTN
RSU 2 3 SUSP EXCIT	58	TBD	TBD	TBD	5	RSU 2 3 SUSP EXCIT
RGA 2 3 CONT THERM LO	59	TBD	TBD	TBD	4	RGA 2 3 CONT THERM LO
RGA 2 3 CONT THERM HI	60	TBD	TBD	TBD	10	RGA 2 3 CONT THERM HI
RGA 2 3 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 2 3 SHIELD GND(4,10)

Table 3-9 ECU-2 to RSU-2 Channel-2 Connector Pin Functions

Description	ECU2 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P2 Pin #	Description
RSU 2 4 -15 VDC	1	TBD	TBD	TBD	37	RSU 2 4 -15 VDC
RSU 2 4 -15 VDC RTN	2	TBD	TBD	TBD	38	RSU 2 4 -15 VDC RTN
RSU 2 4 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	RSU 2 4 SIM TORQ SIG LO
RGA 2 4 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 2 4 SHIELD CARRY THRU(47,46)
RSU 2 4 PWM HI	5	TBD	TBD	TBD	30	RSU 2 4 PWM HI
RSU 2 4 +15 VDC	6	TBD	TBD	TBD	27	RSU 2 4 +15 VDC
RSU 2 4 +15 VDC RTN	7	TBD	TBD	TBD	28	RSU 2 4 +15 VDC RTN
RSU 2 4 +20 VDC RTN	8	TBD	TBD	TBD	36	RSU 2 4 +20 VDC RTN
RSU 2 4 +5 VDC RTN	9	TBD	TBD	TBD	45	RSU 2 4 +5 VDC RTN
RSU 2 4 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	RSU 2 4 SIM TORQ SIG HI
RSU 2 4 MODE CMD	11	TBD	TBD	TBD	54	RSU 2 4 MODE CMD
RSU 2 4 307.2 KHZ HI	12	TBD	TBD	TBD	48	RSU 2 4 307.2 KHZ HI
RGA 2 4 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 2 4 SHIELD GND(48,49)
RSU 2 4 PWM LO	14	TBD	TBD	TBD	31	RSU 2 4 PWM LO
RSU 2 4 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	RSU 2 4 9.6 KHZ REF LO
RSU 2 4 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	RSU 2 4 9.6 KHZ REF HI
RGA 2 4 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 2 4 SHIELD GND(20,19)
RSU 2 4 +20 VDC	20	TBD	TBD	TBD	26	RSU 2 4 +20 VDC
RGA 2 4 SHIELD	21	TBD	TBD	TBD	35	RGA 2 4 SHIELD

Description	ECU2 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P2 Pin #	Description
GND(39,40)						GND(34,43)
RSU 2 4 +5 VDC	23	TBD	TBD	TBD	52	RSU 2 4 +5 VDC
RSU 2 4 SIM TORQ ENBL	24	TBD	TBD	TBD	53	RSU 2 4 SIM TORQ ENBL
RGA 2 4 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 2 4 SHIELD GND(54,43)
RSU 2 4 307.2 KHZ LO	27	TBD	TBD	TBD	49	RSU 2 4 307.2 KHZ LO
RGA 2 4 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 2 4 SHIELD GND(50,42)
RGA 2 4 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 2 4 SHIELD GND(30,31)
RSU 2 4 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	RSU 2 4 WHL DRIVE PHASE B HI
RGA 2 4 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 2 4 SHIELD GND(14,13)
RSU 2 4 SYNC LO	32	TBD	TBD	TBD	14	RSU 2 4 SYNC LO
RSU 2 4 SYNC HI	33	TBD	TBD	TBD	13	RSU 2 4 SYNC HI
RGA 2 4 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	RGA 2 4 CONTROL SENSOR LO
RGA 2 4 CONTROL SENSOR HI	37	TBD	TBD	TBD	17	RGA 2 4 CONTROL SENSOR HI
RGA 2 4 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 2 4 SHIELD GND(18,17)
RSU 2 4 RATE IN HI	39	TBD	TBD	TBD	34	RSU 2 4 RATE IN HI
RSU 2 4 RATE IN LO	40	TBD	TBD	TBD	43	RSU 2 4 RATE IN LO
RGA 2 4 SHIELD GND(43,44)	42	TBD	TBD	TBD	64	RGA 2 4 SHIELD GND(65,66)
RSU 2 4 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	RSU 2 4 GYRO TMP MON SENS HI

Description	ECU2 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P2 Pin #	Description
RSU 2 4 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	RSU 2 4 GYRO TMP MON SENS LO
RGA 2 4 SURV HEATER MON	45	TBD	TBD	TBD	62	RGA 2 4 SURV HEATER MON
RGA 2 4 SURV HEATER +28V	46	TBD	TBD	TBD	57	RGA 2 4 SURV HEATER +28V
RGA 2 4 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	RGA 2 4 SURV HEATER +28V RTN
RGA 2 4 NORM HEATER HI	48	TBD	TBD	TBD	50	RGA 2 4 NORM HEATER HI
RGA 2 4 NORM HEATER LO	49	TBD	TBD	TBD	42	RGA 2 4 NORM HEATER LO
RSU 2 4 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	RSU 2 4 WHL DRIVE PHASE B LO
RGA 2 4 SHIELD GND(30,51)	52	TBD	TBD	TBD	16	RGA 2 4 SHIELD GND(23,24)
RSU 2 4 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	RSU 2 4 WHL DRIVE PHASE A LO
RSU 2 4 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	RSU 2 4 WHL DRIVE PHASE A HI
RGA 2 4 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 2 4 SHIELD GND(9,8)
RGA 2 4 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 2 4 SHIELD GND(1,5)
RSU 2 4 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	RSU 2 4 SUSP EXCIT RTN
RSU 2 4 SUSP EXCIT	58	TBD	TBD	TBD	5	RSU 2 4 SUSP EXCIT
RGA 2 4 CONT THERM LO	59	TBD	TBD	TBD	4	RGA 2 4 CONT THERM LO
RGA 2 4 CONT THERM	60	TBD	TBD	TBD	10	RGA 2 4 CONT

Description	ECU2 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU2 P2 Pin #	Description
HI						THERM HI
RGA 2 4 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 2 4 SHIELD GND(4,10)

Table 3-10 ECU-3 to RSU-3 Channel-1 Connector Pin Functions

Description	ECU3 P5 Pin #	GIU3 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P1 Pin #	Description
RSU 3 5 -15 VDC	1	TBD	TBD	TBD	37	RSU 3 5 -15 VDC
RSU 3 5 -15 VDC RTN	2	TBD	TBD	TBD	38	RSU 3 5 -15 VDC RTN
RSU 3 5 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	RSU 3 5 SIM TORQ SIG LO
RGA 3 5 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 3 5 SHIELD CARRY THRU(47,46)
RSU 3 5 PWM HI	5	TBD	TBD	TBD	30	RSU 3 5 PWM HI
RSU 3 5 +15 VDC	6	TBD	TBD	TBD	27	RSU 3 5 +15 VDC
RSU 3 5 +15 VDC RTN	7	TBD	TBD	TBD	28	RSU 3 5 +15 VDC RTN
RSU 3 5 +20 VDC RTN	8	TBD	TBD	TBD	36	RSU 3 5 +20 VDC RTN
RSU 3 5 +5 VDC RTN	9	TBD	TBD	TBD	45	RSU 3 5 +5 VDC RTN
RSU 3 5 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	RSU 3 5 SIM TORQ SIG HI
RSU 3 5 MODE CMD	11	TBD	TBD	TBD	54	RSU 3 5 MODE CMD
RSU 3 5 307.2 KHZ HI	12	TBD	TBD	TBD	48	RSU 3 5 307.2 KHZ HI
RGA 3 5 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 3 5 SHIELD GND(48,49)
RSU 3 5 PWM LO	14	TBD	TBD	TBD	31	RSU 3 5 PWM LO
RSU 3 5 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	RSU 3 5 9.6 KHZ REF LO
RSU 3 5 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	RSU 3 5 9.6 KHZ

Description	ECU3 P5 Pin #	GIU3 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P1 Pin #	Description
						REF HI
RGA 3 5 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 3 5 SHIELD GND(20,19)
RSU 3 5 +20 VDC	20	TBD	TBD	TBD	26	RSU 3 5 +20 VDC
RGA 3 5 SHIELD GND(39,40)	21	TBD	TBD	TBD	35	RGA 3 5 SHIELD GND(34,43)
RSU 3 TEMP SENSOR LO	22	TBD	TBD	TBD	51	RSU 3 TEMP SENSOR LO
RSU 3 5 +5 VDC	23	TBD	TBD	TBD	52	RSU 3 5 +5 VDC
RSU 3 5 SIM TORQ ENBL	24	TBD	TBD	TBD	53	RSU 3 5 SIM TORQ ENBL
RGA 3 5 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 3 5 SHIELD GND(54,43)
RGA 3 5 SHIELD GND(22,41)	26	TBD	TBD	TBD	61	RGA 3 5 SHIELD GND(22,41)
RSU 3 5 307.2 KHZ LO	27	TBD	TBD	TBD	49	RSU 3 5 307.2 KHZ LO
RGA 3 5 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 3 5 SHIELD GND(50,42)
RGA 3 5 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 3 5 SHIELD GND(30,31)
RSU 3 5 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	RSU 3 5 WHL DRIVE PHASE B HI
RGA 3 5 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 3 5 SHIELD GND(14,13)
RSU 3 5 SYNC LO	32	TBD	TBD	TBD	14	RSU 3 5 SYNC LO
RSU 3 5 SYNC HI	33	TBD	TBD	TBD	13	RSU 3 5 SYNC HI
RGA 3 5 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	RGA 3 5 CONTROL SENSOR LO
RGA 3 5 CONTROL	37	TBD	TBD	TBD	17	RGA 3 5 CONTROL

Description	ECU3 P5 Pin #	GIU3 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P1 Pin #	Description
SENSOR HI						SENSOR HI
RGA 3 5 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 3 5 SHIELD GND(18,17)
RSU 3 5 RATE IN HI	39	TBD	TBD	TBD	34	RSU 3 5 RATE IN HI
RSU 3 5 RATE IN LO	40	TBD	TBD	TBD	43	RSU 3 5 RATE IN LO
RSU 3 TEMP SENSOR HI	41	TBD	TBD	TBD	44	RSU 3 TEMP SENSOR HI
RGA 3 5 SHIELD GND(43,44)	42	TBD	TBD	TBD	64	RGA 3 5 SHIELD GND(65,66)
RSU 3 5 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	RSU 3 5 GYRO TMP MON SENS HI
RSU 3 5 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	RSU 3 5 GYRO TMP MON SENS LO
RGA 3 5 SURV HEATER MON	45	TBD	TBD	TBD	62	RGA 3 5 SURV HEATER MON
RGA 3 5 SURV HEATER +28V	46	TBD	TBD	TBD	57	RGA 3 5 SURV HEATER +28V
RGA 3 5 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	RGA 3 5 SURV HEATER +28V RTN
RGA 3 5 NORM HEATER HI	48	TBD	TBD	TBD	50	RGA 3 5 NORM HEATER HI
RGA 3 5 NORM HEATER LO	49	TBD	TBD	TBD	42	RGA 3 5 NORM HEATER LO
RSU 3 5 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	RSU 3 5 WHL DRIVE PHASE B LO
RGA 3 5 SHIELD	52	TBD	TBD	TBD	16	RGA 3 5 SHIELD

Description	ECU3 P5 Pin #	GIU3 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P1 Pin #	Description
GND(30,51)						GND(23,24)
RSU 3 5 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	RSU 3 5 WHL DRIVE PHASE A LO
RSU 3 5 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	RSU 3 5 WHL DRIVE PHASE A HI
RGA 3 5 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 3 5 SHIELD GND(9,8)
RGA 3 5 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 3 5 SHIELD GND(1,5)
RSU 3 5 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	RSU 3 5 SUSP EXCIT RTN
RSU 3 5 SUSP EXCIT	58	TBD	TBD	TBD	5	RSU 3 5 SUSP EXCIT
RGA 3 5 CONT THERM LO	59	TBD	TBD	TBD	4	RGA 3 5 CONT THERM LO
RGA 3 5 CONT THERM HI	60	TBD	TBD	TBD	10	RGA 3 5 CONT THERM HI
RGA 3 5 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 3 5 SHIELD GND(4,10)

Table 3-11 ECU-3 to RSU-3 Channel-2 Connector Pin Functions

Description	ECU3 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P2 Pin #	Description
RSU 3 6 -15 VDC	1	TBD	TBD	TBD	37	
RSU 3 6 -15 VDC RTN	2	TBD	TBD	TBD	38	
RSU 3 6 SIM TORQ SIG LO	3	TBD	TBD	TBD	47	
RGA 3 6 SHIELD CARRY THRU(3,10)	4	TBD	TBD	TBD	39	RGA 3 6 SHIELD CARRY THRU(47,46)
RSU 3 6 PWM HI	5	TBD	TBD	TBD	30	
RSU 3 6 +15 VDC	6	TBD	TBD	TBD	27	
RSU 3 6 +15 VDC RTN	7	TBD	TBD	TBD	28	
RSU 3 6 +20 VDC RTN	8	TBD	TBD	TBD	36	
RSU 3 6 +5 VDC RTN	9	TBD	TBD	TBD	45	
RSU 3 6 SIM TORQ SIG HI	10	TBD	TBD	TBD	46	
RSU 3 6 MODE CMD	11	TBD	TBD	TBD	54	
RSU 3 6 307.2 KHZ HI	12	TBD	TBD	TBD	48.	
RGA 3 6 SHIELD GND(12,27)	13	TBD	TBD	TBD	40	RGA 3 6 SHIELD GND(48,49)
RSU 3 6 PWM LO	14	TBD	TBD	TBD	31	
RSU 3 6 9.6 KHZ REF LO	17	TBD	TBD	TBD	20	
RSU 3 6 9.6 KHZ REF HI	18	TBD	TBD	TBD	19	
RGA 3 6 SHIELD GND(17,18)	19	TBD	TBD	TBD	12	RGA 3 6 SHIELD GND(20,19)
RSU 3 6 +20 VDC	20	TBD	TBD	TBD	26	
RGA 3 6 SHIELD GND(39,40)	21	TBD	TBD	TBD	35	RGA 3 6 SHIELD GND(34,43)
RSU 3 6 +5 VDC	23	TBD	TBD	TBD	52	
RSU 3 6 SIM TORQ ENBL	24	TBD	TBD	TBD	53	

Description	ECU3 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P2 Pin #	Description
RGA 3 6 SHIELD GND(11,24)	25	TBD	TBD	TBD	55	RGA 3 6 SHIELD GND(54,43)
RSU 3 6 307.2 KHZ LO	27	TBD	TBD	TBD	49	
RGA 3 6 SHIELD GND(48,49)	28	TBD	TBD	TBD	41	RGA 3 6 SHIELD GND(50,42)
RGA 3 6 SHIELD GND(5,14)	29	TBD	TBD	TBD	32	RGA 3 6 SHIELD GND(30,31)
RSU 3 6 WHL DRIVE PHASE B HI	30	TBD	TBD	TBD	23	
RGA 3 6 SHIELD GND(32,33)	31	TBD	TBD	TBD	15	RGA 3 6 SHIELD GND(14,13)
RSU 3 6 SYNC LO	32	TBD	TBD	TBD	14	
RSU 3 6 SYNC HI	33	TBD	TBD	TBD	13	
RGA 3 6 CONTROL SENSOR LO	36	TBD	TBD	TBD	18	
RGA 3 6 CONTROL SENSOR HI	37	TBD	TBD	TBD	17	
RGA 3 6 SHIELD GND(36,37)	38	TBD	TBD	TBD	25	RGA 3 6 SHIELD GND(18,17)
RSU 3 6 RATE IN HI	39	TBD	TBD	TBD	34	
RSU 3 6 RATE IN LO	40	TBD	TBD	TBD	43	
RGA 3 6 SHIELD GND(43,44)	42	TBD	TBD	TBD	64	RGA 3 6 SHIELD GND(65,66)
RSU 3 6 GYRO TMP MON SENS HI	43	TBD	TBD	TBD	65	
RSU 3 6 GYRO TMP MON SENS LO	44	TBD	TBD	TBD	66	
RGA 3 6 SURV HEATER MON	45	TBD	TBD	TBD	62	
RGA 3 6 SURV HEATER	46	TBD	TBD	TBD	57	

Description	ECU3 P6 Pin #	GIU2 Departure I/F Pin #	DM Departure I/F Pin #	WFC3 I/F Pin #	RSU3 P2 Pin #	Description
+28V						
RGA 3 6 SURV HEATER +28V RTN	47	TBD	TBD	TBD	63	
RGA 3 6 NORM HEATER HI	48	TBD	TBD	TBD	50	
RGA 3 6 NORM HEATER LO	49	TBD	TBD	TBD	42	
RSU 3 6 WHL DRIVE PHASE B LO	51	TBD	TBD	TBD	24	
RGA 3 6 SHIELD GND(30,51)	52	TBD	TBD	TBD	16	RGA 3 6 SHIELD GND(23,24)
RSU 3 6 WHL DRIVE PHASE A LO	53	TBD	TBD	TBD	9	
RSU 3 6 WHL DRIVE PHASE A HI	54	TBD	TBD	TBD	8	
RGA 3 6 SHIELD GND(53,54)	55	TBD	TBD	TBD	3	RGA 3 6 SHIELD GND(9,8)
RGA 3 6 SHIELD GND(57,58)	56	TBD	TBD	TBD	2	RGA 3 6 SHIELD GND(1,5)
RSU 3 6 SUSP EXCIT RTN	57	TBD	TBD	TBD	1	
RSU 3 6 SUSP EXCIT	58	TBD	TBD	TBD	5	
RGA 3 6 CONT THERM LO	59	TBD	TBD	TBD	4	
RGA 3 6 CONT THERM HI	60	TBD	TBD	TBD	10	
RGA 3 6 SHIELD GND(59,60)	61	TBD	TBD	TBD	11	RGA 3 6 SHIELD GND(4,10)

Table 3-12 ECU-1 Power Connector Pin Functions

ECU#	Connector #	Pin #	Description
ECU1	P3	1	RGA 1 1 PWR RTN
ECU1	P3	2	RGA 1 1 OP HTR PWR RTN
ECU1	P3	3	RGA 1 1 OP HTR PWR RTN
ECU1	P3	4	RGA 1 1 OP HTR PWR
ECU1	P3	5	RGA 1 1 PWR
ECU1	P3	6	RGA 1 1 PWR
ECU1	P3	7	RGA 1 1 PWR RTN
ECU1	P3	8	RGA 1 1 SURV HTR PWR
ECU1	P3	9	RGA 1 1 SURV HTR PWR RTN
ECU1	P3	10	RGA 1 1 SURV HTR PWR RTN
ECU1	P3	11	RGA 1 1 SURV HTR PWR
ECU1	P3	12	RGA 1 1 OP HTR PWR
ECU1	P4	1	RGA 1 2 PWR RTN
ECU1	P4	2	RGA 1 2 OP HTR PWR RTN
ECU1	P4	3	RGA 1 2 OP HTR PWR RTN
ECU1	P4	4	RGA 1 2 OP HTR PWR
ECU1	P4	5	RGA 1 2 PWR
ECU1	P4	6	RGA 1 2 PWR
ECU1	P4	7	RGA 1 2 PWR RTN
ECU1	P4	8	RGA 1 2 SURV HTR PWR
ECU1	P4	9	RGA 1 2 SURV HTR PWR RTN
ECU1	P4	10	RGA 1 2 SURV HTR PWR RTN
ECU1	P4	11	RGA 1 2 SURV HTR PWR
ECU1	P4	12	RGA 1 2 OP HTR PWR

Table 3-13 ECU-2 Power Connector Pin Functions

ECU#	Connector #	Pin #	Description
ECU2	P3	1	RGA 2 3 PWR RTN
ECU2	P3	2	RGA 2 3 OP HTR PWR RTN
ECU2	P3	3	RGA 2 3 OP HTR PWR RTN
ECU2	P3	4	RGA 2 3 OP HTR PWR
ECU2	P3	5	RGA 2 3 PWR
ECU2	P3	6	RGA 2 3 PWR
ECU2	P3	7	RGA 2 3 PWR RTN
ECU2	P3	8	RGA 2 3 SURV HTR PWR
ECU2	P3	9	RGA 2 3 SURV HTR PWR RTN
ECU2	P3	10	RGA 2 3 SURV HTR PWR RTN
ECU2	P3	11	RGA 2 3 SURV HTR PWR
ECU2	P3	12	RGA 2 3 OP HTR PWR
ECU2	P4	1	RGA 2 4 PWR RTN
ECU2	P4	2	RGA 2 4 OP HTR PWR RTN
ECU2	P4	3	RGA 2 4 OP HTR PWR RTN
ECU2	P4	4	RGA 2 4 OP HTR PWR
ECU2	P4	5	RGA 2 4 PWR
ECU2	P4	6	RGA 2 4 PWR
ECU2	P4	7	RGA 2 4 PWR RTN
ECU2	P4	8	RGA 2 4 SURV HTR PWR
ECU2	P4	9	RGA 2 4 SURV HTR PWR RTN
ECU2	P4	10	RGA 2 4 SURV HTR PWR RTN
ECU2	P4	11	RGA 2 4 SURV HTR PWR
ECU2	P4	12	RGA 2 4 OP HTR PWR

Table 3-14 ECU-3 Power Connector Pin Functions

ECU#	Connector #	Pin #	Description
ECU3	P3	1	RGA 3 5 PWR RTN
ECU3	P3	2	RGA 3 5 OP HTR PWR RTN
ECU3	P3	3	RGA 3 5 OP HTR PWR RTN
ECU3	P3	4	RGA 3 5 OP HTR PWR
ECU3	P3	5	RGA 3 5 PWR
ECU3	P3	6	RGA 3 5 PWR
ECU3	P3	7	RGA 3 5 PWR RTN
ECU3	P3	8	RGA 3 5 SURV HTR PWR
ECU3	P3	9	RGA 3 5 SURV HTR PWR RTN
ECU3	P3	10	RGA 3 5 SURV HTR PWR RTN
ECU3	P3	11	RGA 3 5 SURV HTR PWR
ECU3	P3	12	RGA 3 5 OP HTR PWR
ECU3	P4	1	RGA 3 6 PWR RTN
ECU3	P4	2	RGA 3 6 OP HTR PWR RTN
ECU3	P4	3	RGA 3 6 OP HTR PWR RTN
ECU3	P4	4	RGA 3 6 OP HTR PWR
ECU3	P4	5	RGA 3 6 PWR
ECU3	P4	6	RGA 3 6 PWR
ECU3	P4	7	RGA 3 6 PWR RTN
ECU3	P4	8	RGA 3 6 SURV HTR PWR
ECU3	P4	9	RGA 3 6 SURV HTR PWR RTN
ECU3	P4	10	RGA 3 6 SURV HTR PWR RTN
ECU3	P4	11	RGA 3 6 SURV HTR PWR
ECU3	P4	12	RGA 3 6 OP HTR PWR

3.3.1.8 HST486 Mechanical Interface

HST486 mechanical interfaces shall be as defined in GSFC drawing GE2021299. The J9 test connector is capped and is located on the +V1 face. The HST 486 connector shall be LJT07RE-13-8S(453)(TBR-Mating Half).

3.3.1.8.1 HST486 Pin Outs

The HST486 P9 connector pin outs are provided in Table 3-15.

3.3.1.9 GIU to 1553 Input/Output (I/O) Mechanical Interface

The 1553 connector to the HST486 shall be LJT07RE-13-8S(453)(TBR-Mating Half (GFE)).

Table 3-15 HST486 P9 Connector Pin Functions

Pin	Signal Description
A	1553A+
B	1553A-
C	1553AGND
D	1553B+
E	1553B-
F	1553BGND
G	HST486 Chassis Ground
H	SPARE

3.3.1.10 NICMOS Cooling System (NCS) Power Augmentation Mechanical Interface

The NCS Power connector is NCS Radiator Diode Box J1, BL00F23-21N (935), and the pin functions are provided in Table 3-16.

3.3.1.11 HRV to HST Connector Interface Plate

The HRV to HST Connector Interface Plate shall be a rack and panel similar to GSFC drawing GD 2033311 and layout shall be (**TBD**). The location of the connector interface plate shall be ≥ **(TBD)**.

3.3.1.12 Alignment

The HRV/HST interface design shall provide the capability for attaching and maintaining the alignment of the HRV to the HST to ensure that their reference axes are aligned to an accuracy of ± 0.5 degree in all axes.

3.3.1.13 Venting and Purge

N/A

Table 3-16 NCS Radiator Diode Box J1 Connector Pin Functions

Pin	Signal Description	Pin	Signal Description
A	Battery Bus 1 (HST 28 Vdc power)	L	Battery Bus 6 (HST 28 Vdc power)
B	Unregulated Bus Return	M	Unregulated Bus Return
C	Battery Bus 2 (HST 28 Vdc power)	N	Transfer Switch S1 Power (HST 28 Vdc power, powers NCS Survival Heater Bus A)
D	Unregulated Bus Return	P	Unregulated Bus Return
E	Battery Bus 3 (HST 28 Vdc power)	R	Transfer Switch S2 Power (HST 28 Vdc power, powers NCS Survival Heater Bus B)
F	Unregulated Bus Return	S	Unregulated Bus Return
G	Battery Bus 4 (HST 28 Vdc power)	T	NC
H	Unregulated Bus Return	U	NC
J	Battery Bus 5 (HST 28 Vdc power)	V	NC
K	Unregulated Bus Return	W	NC
		X	Chassis Ground

3.3.1.14 Ground Support Equipment

Ground processing requires the HRV –V1 access to be either horizontal or up (i.e. +V1 down for Launch vehicle integration). HRV –V1 horizontal requires +V3 to be either up (SA flash testing) or down (ORU/ORI installation/removal).

3.3.1.15 Mass Properties

3.3.1.15.1 HST Mass Properties

The mass of the HST is 26745 lbs. (12129.3 kg)
The center of gravity is:

V1=254.3 inches (6.46m)
V2=1.0 inches (0.03m)
V3=-7.5 inches (-0.19m)

The moment of inertia of the central rigid body, HST, will be no less than:

Iv1 = 27669 slug ft2 (37503 kg m2)
Iv2 = 68835 slug ft2 (90590 kg m2)
Iv3 = 71112 slug ft2 (96387 kg m2)

The HST Mass Properties Report is provided in ST/SE-04.

3.3.1.15.2 HST/HRV Inertia Limit

The combined HST and any portion of the HRV that remains attached for science operations shall have maximum inertia of 166,000 kg – m^2.

3.3.1.16 Envelopes

3.3.1.16.1 HST Envelopes

The HST Envelope is defined in Lockheed drawing 4171550 (HST Assembly Complete), 4177659 (Inboard/Outboard Profile) and GSFC drawing GE 1525373 (Exception: ASCS Radiator and conduit was not installed).

3.3.1.16.2 HST Central Body Cross-Sectional Area

The maximum cross-sectional area of the HST central body is 87,200 sq. inches. The minimum cross sectional area of the HST central body is 24,600 sq. inches.

3.3.1.16.2 HST SA3 Cross-Sectional Area

The maximum cross-sectional area of each solar array is 27,600 sq. inches.

3.3.1.17 Fields Of View (FOV)

3.3.1.17.1 Optics

3.3.1.17.1.1 Coarse Sun Sensor (CSS) Clearances

Any module of the HRV that remains attached to HST during science operations shall be designed to maintain the full hemispherical field of view of Coarse Sun Sensors CSS-4 (**TBD**) (reference 3.3.1.3.5 for location).

The HRV shall minimize reflections in the CSS FOV.

Any module of the HRV that remains attached to HST during science operations shall be designed to maintain the full hemispherical field of view of Coarse Sun Sensors CSS-3 and 5 (reference 3.3.1.3.5 for location). CSS-5 is located on the same bracket as CSS-4 (reference 3.3.1.3.5 for location).

3.3.1.17.1.2 Fixed Head Star Trackers (FHSTs)

Rendezvous operations will have the FHSTs closed. The shutters are not completely light-tight and detector sensitivity to (TBD) wave length is (TBD).

3.3.1.17.1.3 HST Primary Optics

Rendezvous operations will nominally have the aperture door closed. Contingency operations with the aperture door opened shall be constrained to a 50 degree +V1 cone of exclusion (from station 240).

3.3.1.17.2 Thermal/Radiators

N/A

3.3.1.17.3 Electrical/Solar Arrays

The HRV SAs shall have an unrestricted field of view such that when the HRV +V3 axis is sun-pointed with (See Figure 3-9) off nominal incidence angles, the HRV SAs are not obscured. In other attitudes SA shadowing will occur.

3.3.1.17.4 Antennas

N/A

3.3.2 Structural Interfaces

3.3.2.1 Launch and Ascent Loads

HRV Launch and Ascent loads are defined in the HRV to Launch Vehicle Interface Control Document.

3.3.2.1.1 Liftoff Loads

The HRV shall limit the Static Load of the:

a) GIU to 22.5 g.
b) P101 main umbilical actuator to **TBD** g.

3.3.2.1.2 Random Mechanical Vibration

The HRV shall limit the Random Vibration level of the:

a) GIU to 14.8 g RMS.
b) P101 main umbilical actuator to **TBD** g RMS.

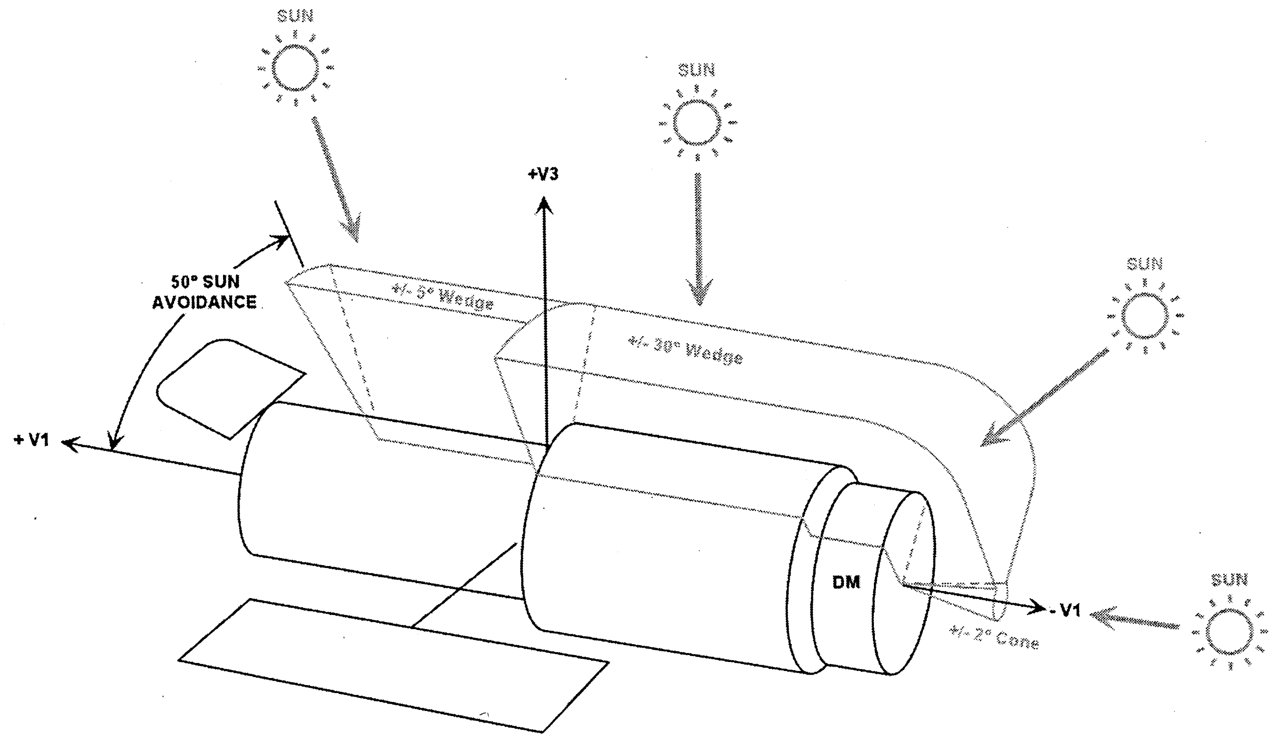


Figure 3-9 HST Sun Position Envelope for Normal Science

3.3.2.1.3 Acoustic Loads

This section is not applicable to HST to HRV interfaces.

3.3.2.1.4 Pressure And Venting Loads

The HRV shall keep unobstructed the vents of the:

a) ECU per Lockheed drawing 4171776-003 and GIU per drawing **TBD**.
b) P101 Main Umbilical Actuator is a open-box structure.

3.3.2.1.5 ELV Pyrotechnic Shock

All HRV structure and components shall survive shock loading due to ELV separations at the separation plane, as defined below (TBR):

a) 100 Hz 50g
b) 100 <Freq<1600HZ +10 dB/octive
c) 1600< Freq<10000Hz 5000g

Note: 1g = standard acceleration due to gravity 9.81 m/s

Verification will be in the form of a spacecraft level shock test.

3.3.2.1.6 Launch Vehicle Resonant Frequency Constraints

All HRV structure shall be designed such that there is no adverse coupling with the ELV resonant frequency, defined by **TBD**.

3.3.2.2 In-Orbit Loads

3.3.2.2.1 Plume Loading

3.3.2.2.1.1 HST Body Plume loading

Plume Loads by HRV on HST, with a maximum surface area as identified in Section 3.3.1.16.1, shall be a maximum of 9.35 in-lbf about its CG as defined in Section 3.3.1.15.1.

3.3.2.2.1.2 SA3 Plume loading

Plume Loads by HRV on HST, with a maximum surface area as identified in Section 3.3.1.16.2, shall be a maximum of 4.5 in-lbf about V2 Axis.**3.3.2.2.2 Grapple Fixture Limit Loads**

The allowable forces at the grapple fixture shall be less than that defined in Table 3-17 and Figure 3-10.

Table 3-17 Grapple Fixture Load Capability

	Axial	Shear	Moment	Torsion
1) Snaring	848 lbs	309 lbs	3600 in-lbs	N/A
2) Clamping	522 lbs	522 lbs	3230 in-lbs	6264 in-lbs

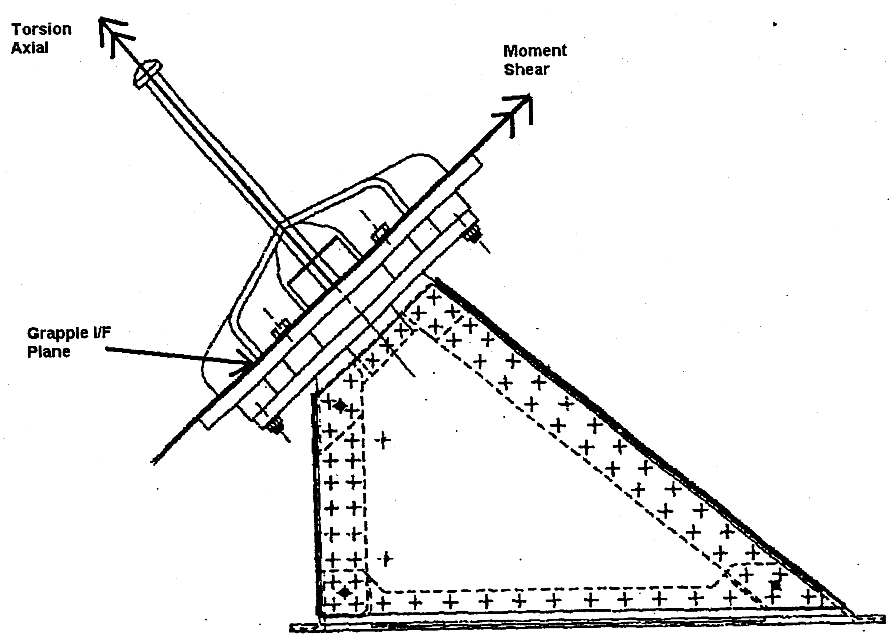


Figure 3-10 Grapple Fixture Load Figure

3.3.2.2.3 FSS Berthing Pins Limit Loads

Any combination of applied forces at the FSS berthing pins shall result in positive margins of safety using the Load Transformation (LT) equations in Table 3-18 and the appropriate factors of safety.

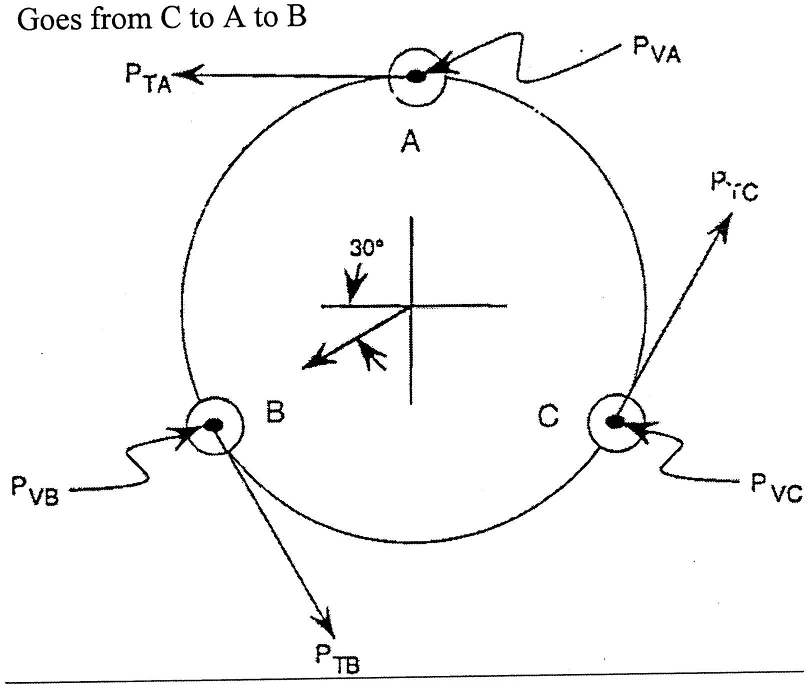
Table 3-18 AB Berthing Pin Capability

The following table defines equations to be used in calculating margins for the Berthing Pin Mounts and Aft bulkhead backup structure. Factors of Safety shall be untested as specified in Section 4.1.1.5.1.

Item	*Equation*	*Allow*
Berthing Pin Mount:		
Mount Post (Bending)	$\lvert 1.0\, P_{Ti} \rvert$	2370
Berthing Pin (Bending)	$\lvert (0.261\, P_{Ti} + 0.261\, P_{Vi}) \rvert$ →	2017
Mount Base (Bending)	$\lvert 1.0\, P_{Ti} \rvert$	2096
Aft Bulkhead:		
Beam Stiffener (Bending)	$\lvert (0.763\, P_{Vi} + 0.108\, P_{Vj} + 0.108\, P_{Vk} + 0.017\, P_{Tj} + 0.017\, P_{Tk}) \rvert$	2017
Cap/Web Bond	$\lvert (1.0\, P_{Vi} + 0.154\, P_{Vj} + 0.154\, P_{Vk}) \rvert$	1610
Bulkhead Center Splice(Shear)	$\lvert (1.0\, P_{Vi} + 1.0\, P_{Vj} + 1.0\, P_{Vk}) \rvert$	3129
Facesheet	$\lvert (0.424\, P_{Vi} + 0.231\, P_{Vj} + 0.231\, P_{Vk} + 0.93\, P_{Ti} + 0.02\, P_{Tj} + 0.02\, P_{Tk}) \rvert$	2017
Core	$\lvert 1.0\, P_{Vi} \rvert$	1477

NOTE: Each item has 3 equations associated with it. Referring to the figure below, i, j, and k represent pin locations on the HST aft bulkhead

(i) Goes from A to B to C
(j) Goes from B to C to A
(k) Goes from C to A to B



3.3.2.2.3.1 Backup Capture Interface Loads

The maximum loads imparted to the trunnions/keel fitting are as follows:

	Allowables (lbs)
Aft Trunnion z (V3) x (V1)	 81106 106340
Keel Fitting: y (V2)	85625

The table defines capabilities to be used in calculating margins for the trunnions. Factors of Safety shall be untested as specified in Section 4.1.1.5.1.

3.3.2.2.4 General ERC Imposed Loads

3.3.2.2.4.1 Equipment Installation

To install or replace equipment, ERC induced loads shall not exceed 10 lbs represented as a half-sine pulse of duration from 1.0 to 4.0 seconds.

3.3.2.2.4.2 Use of Handrails or Portable Foot Restraint (PFR) Sockets

If handrails or PFR sockets are used for stability, loads shall be limited to 50 lb axial, and 10 lb radial, represented as one cycle of a sine wave of 1.333 Hz.

3.3.2.2.5 HST Appendage Allowable Accelerations

The allowable accelerations at the HST cg shall be less than or equal to 0.1 g.

3.3.2.2.6 Pyrotechnic Shock

The maximum expected separation shock is as specified in 3.3.2.1.5.

3.3.2.2.6.1 HRV Pyrotechnic Shock

The GFE shall be evaluated against this additional pyro-shock requirement. The evaluation shall be conducted for the:

a) GIU to pyro shock loads are **TBD**.
b) P101 main umbilical actuator to pyro shock loads are **TBD**.

3.3.2.2.7 Main Umbilical Actuator

The HRV shall be capable of carrying a maximum torque of 1034 in-lbs about an axis orthogonal to the actuators direction of travel.

3.3.2.3 Interface Stiffness

Any module of the HRV that remains attached to HST during science operations shall have a combined first lateral body mode of 9 hz (**TBR**). An HST Craig-Bampton model will be provided as GFE.

3.3.2.3.1 Harness Stiffness

The ECU to RSU harness stiffness between the HRV and the HST shall not be greater than 1 lb/in.

3.3.2.3.1.1 Harness Routing

The routing of harnesses on HST shall be secured at a maximum of every 10 feet.

3.3.2.3.2 HST Attached Resonant Frequency Constraints

During Servicing the thruster pulses shall be limited to minimize SA3 excitement to **TBD** frequencies.

3.3.2.4 Ground Handling and Transportation Loads

Ground handling loads shall be enveloped by the flight loads. HRV ground handling loads are defined in the DM to EM ICD.

3.3.2.5 Reaction Torques

3.3.2.5.1 Liquid Slosh

Propellant in tanks located in any module that remains berthed to HST during science operations shall have maximum modal gains, Kb of $\leq$ 0.02 from 0 to 1hz, and $\leq$ 0.01 greater than 1 hz (**TBR**).

3.3.3 Environmental Interfaces

3.3.3.1 Thermal Interfaces

3.3.3.1.1 DM to HST Mount Point Conductance

The HRV shall be able to latch to the HST bulkhead when the bulkhead temperature is between –80°C and +5°C. The HRV when attached to the HST, the HST bulkhead temperatures are expected to be between –30° to 11°C.

The conductive transfer of heat between the HRV and HST, when docked, shall be less than or equal to 5 watts. The maximum effective thermal conductance of the three berthing pin attachment points is **TBD** W/°C.

3.3.3.1.2 Electrical Cable and Ground Strap Conductances

Cable effective conductances (K) are less than or equal to 0.1 watt/°C (**TBR**).

3.3.3.1.3 Radiative Heat Transfer

The radiative heat transfer between the DM and HST shall be less than 10 watts when docked to the HST.

3.3.3.1.4 Surface Properties

The GFE surface properties of the:

a) GIU are (α/ε) 0.96/0.87 (TBR).

b) P101 main umbilical actuator are (α/ε) **TBD**.

The GFE thermal capacity of the:

a) GIU is 3.46 BTU/°F (TBR).

b) P101 main umbilical actuator is **TBD** BTU/°F.

3.3.3.1.5 Operational Thermal Interface

When the GFE is operational the HRV shall maintain the temperature of the:

a) GIU to between -24 to 60°C (TBR).

b) P101 main umbilical actuator to between **TBD**°C.

3.3.3.1.5.1 Thermal Power (TBD)

3.3.3.1.5.2 Thermal Power Mode Definitions (TBD)

3.3.3.1.5.3 Thermal Power Mode Constraints (TBD)

3.3.3.1.5.4 Normal Science Mission Thermal Power Configuration (TBD)

3.3.3.1.6 Non-Operational Thermal Interfaces

When the GFE is non-operational the HRV shall maintain the temperature of the:

a) GIU to between -45 to 60°C (TBR).

b) P101 main umbilical actuator to between **TBD**°C.

3.3.3.2 Magnetic Field Environments

3.3.3.2.1 Geomagnetic Fields.

During science observations, the maximum time varying component of the earth's magnetic field is 0.33 gauss. The constant component of the earth magnetic field is 0.21 gauss and is inclined by 65 degrees to the time varying component.

3.3.3.2.2 ST Internal Fields.

The HRV design shall be compatible with the magnetic fields generated and induced by HST and HRV components while subjected to the earth's magnetic field. In addition to the earth's field, the HRV design shall comply with the following magnetic field interfaces.

3.3.3.2.2.1 HST Magnetic Fields.

The maximum magnetic field caused by the HST at any attitude does not exceed the following levels:

a. A level of 0.3 gauss time varying field within the HST volume at station plane 100.
b. A level of 0.10 gauss constant magnetic field within the HST volume at station plane 100.

3.3.3.2.3 HRV Magnetic Fields

The maximum magnetic field caused by the HRV at the boundary of the HST, during HST controlled operations, shall be less than the following levels:

time varying - 0.25 gauss; constant - 0.10 gauss

3.3.3.3 Contamination Control

3.3.3.3.1 Surface Cleanliness

All exterior surfaces shall be Visibly Clean Highly Sensitive per STR-29. Enclosures for aft shroud hardware shall have an interior cleanliness of Level 400B per MIL-STD-1246.

3.3.3.3.2 Material Outgassing

The long term outgassing fluence to the HST AB vents of material condensable at -20 C shall be less than 1e-6 g over science mission life.

3.3.3.3.3 Purge System Interfaces

N/A

3.3.3.3.4 ERC Constraints

N/A

3.3.3.3.5 Plume Impingement

Total mass fluence during AR&C of a controlled HST per Section 3.3.2.2.1 shall be limited to 3.6e-8 g/cm2 (TBR).

3.3.3.4 Ionizing Particle Radiation

The omni-directional ionizing particle environment is specified in Table 3-19.

TABLE 3-19 MAXIMUM INTERNAL IONIZING PARTICLE RADIATION

Trapped Electrons

Cumulative Fluence:	4.55×10^{11} e/cm^2:	E>0.5 MeV
	8.27×10^{10}	1
	1.40×10^{10}	2
	1.06×10^{9}	3
	5.72×10^{7}	4

Trapped Electron Ionizing Dose: 6.5×10^2 rads(Si)
Maximum Electron Flux: 3.255×10^4 e/cm^2-sec: E>0.5 MeV
Maximum Dose Rates: 7.3×10^{-4} rads(Si)/sec

Trapped Protons

Cumulative Fluence:	2.2×10^{10} p/cm^2:	E>4 MeV
	2.27×10^{10}	10
	1.98×10^{10}	20
	1.81×10^{10}	30
	1.78×10^{10}	40
	1.50×10^{10}	50
	1.12×10^{10}	100

Trapped Proton Ionizing Dose: 4.3×10^3 rads(Si)
Maximum Proton Flux: 3.6×10^3 p/cm^2-sec: E>4 MeV
Maximum Dose Rate: $7 \text{ X } 10^{-4}$ rads(Si)/Sec

Total Trapped Proton plus Trapped Electron
Ionizing Dose: 4.95×10^3 rads(Si)

NOTES:

(1) The values stated above are based on predicted external radiation conditions during Solar Minimum for the 5-year period.

(2) The maximum dose rates are calculated for traversals through the South Atlantic geomagnetic anomaly.

3.3.3.5 Meteoroid

Meteoroid protection supplied by the HRV when subjected to the meteoroid flux model as defined in NASA TM 100-471 shall provide a probability of no failure of at least 0.99.

3.3.3.6 Orbital Debris

Orbital debris protection supplied by the HRV shall use the orbital debris flux model as defined in NASA TM-100-471 (**TBR**).

3.3.3.7 Ground Environments (Humidity, etc.)

During all ground and prelaunch (except transportation and storage), the HRV environment shall be maintained at 18.3 deg C(65 deg F) to 26.7 deg C (80 deg F). The HRV temperature environment shall change less than 2.7 deg C (5 deg F) per hour. Relative humidity shall be 30 to 70 percent.

During transportation and storage, the environment shall be controlled to the following requirements:

a. Temperature: 10 deg C (50 deg F) min., 32.2 deg C (90 deg F) max.
b. Temperature change: ll.l deg C (20 deg F) per hour max.
c. Relative humidity: 0 to 70% max.
d. Pressure: .34 to 1.07 ATM max.

3.3.4 Electrical Power System

3.3.4.1 Input Power from SA3

The DM interface to each circuit defined in Tables 3-3 and 3-4 shall be capable of supporting a maximum of 2.4 Amps. The SA3 EOL string level I/V curve is defined in Figure 3-11. Only HST circuits identified as SA3 strings are used at the interface connector.

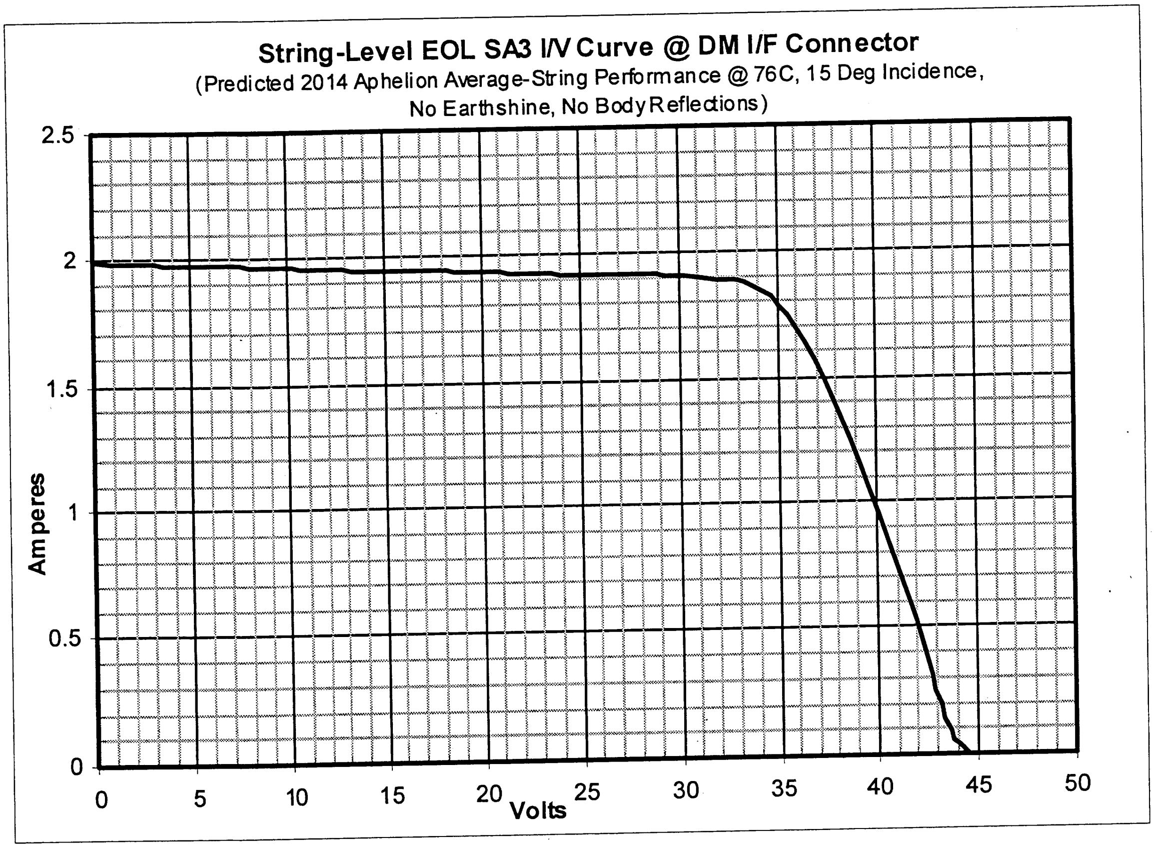


Figure 3-11 SA3 EOL string level I/V curve

3.3.4.2 HST Battery Augmentation Capacity

The DM shall provide 300 Amp hour (**TBR**) of battery capacity of HST utilization at science mission end-of-life.

3.3.4.3 NCS Power Augmentation

The HRV shall provide augmentation power for the NCS with a maximum of 460 watts. This is a subset of the total power as defined in Section 3.2.4.1.

3.3.4.4 Power Buses

The HRV shall supply two switched power buses for HST operating power.

Each bus conforms to the requirements specified in the following paragraphs. Under normal operating conditions the SSM powers all power buses simultaneously.

3.3.4.5 Circuit Protection

The HRV design shall incorporate fault protection to isolate electrical shorts occurring within the HRV equipment per EEE-INST-002. Circuit protection shall be sized to ensure that faults are isolated downstream of the power bus(es).

For HST J101, P105 and P106 interfaces, current protection for each HST Main bus power feed of 25 Amps and for each HST Essential Power bus feed of 5 Amps shall be provided.

The HRV power source feeding the HST umbilical shall be current limited to 125 Amps maximum.

For HST NCS Radiator Diode Box J1 interface, current protection for each battery bus power feed of 15 Amps and for each transfer switch bus feed of 10 Amps shall be provided.

3.3.4.6 Switching

The HRV shall provide a switching capability to all non-critical loads. All switching devices shall comply with (**TBR**).

3.3.4.7 Operating Voltage

The HRV shall provide an operating voltage range at the HST umbilical of 29.2 Vdc to 33.5 Vdc open circuit.

3.3.4.8 No Single Point Failure

No single point failure shall result in the inability to execute the HRV mission objectives.

3.3.4.9 GFE Power

The HRV shall provide power for the:

a) GIU:

		Watts per Channel
	Steady-state:	20 (TBR)
RSU Survival Heater Power	(@32 V):	70 (Peak)
Operational Heater Power	(@32V):	50 (Peak)

Voltage range for all GIU power services is 24 to 32 volts.

b) P101 main umbilical actuator of up to **TBS** watts.

3.3.4.10 Grounding of Interface

3.3.4.10.1 Mount Point Fitting Resistance

The HST main umbilical (P101/J101) has structure ground interfaces.

3.3.4.10.2 Multi-Layer Insulation (MLI)

3.3.4.10.3 Non Conductive Surfaces

3.3.4.11 Electromagnetic Compatibility (EMC)

The HRV shall be electromagnetically compatible with the HST as specified in the following paragraphs.

3.3.4.11.1 HRV Power Bus Ripple and Noise

3.3.4.11.2 In-Rush Current

In-rush current rise and fall times shall be limited to less than 6 amps/microsecond.

3.3.4.11.3 Generated Ripple & Noise

The HRV shall not generate ripple and noise on the power lines in excess of the values shown in Figures 3-12, 3-13, 3–14, 3-15. These values apply at 30 ± 0.5 Vdc. Test method will be in accordance with MIL-STD-462, methods CE01 and CE03.

3.3.4.11.4 Ripple and Noise Susceptibility

The HRV shall not be susceptible to ripple and noise on the power lines. Susceptibility limits are shown in Figure 3-16. These values apply at 30 ± 0.5 Vdc. Test method will be in accordance with MIL-STD-462, methods CS01 and CS02.

3.3.4.11.5 Transient Susceptibility

The HRV shall not be susceptible to transients that may appear on the power lines, and between power line return and structure. Figure 3-17 defines the transient waveforms. These values apply at 30 ± 0.5 Vdc. Test method will be in accordance with MIL-STD-462, method CS06.

3.3.4.11.6 Survival

During ground operations testing, the HRV shall provide uninterruptible backup power.

3.3.4.11.7 Radiated Susceptibility (E-Field)

The HRV shall not be degraded in performance when subjected to the following radiated fields. Test method will be in accordance with MIL-STD-462, method RS03.

14 KHz to 35 MHz	2 volt/meter CW (continuous wave)
35 MHz to 2 GHz	2 volt/meter AM (modulation peak amplitude)
2GHz to 12 GHz	5 volts/meter AM (modulation peak amplitude)
12 GHz to 18 GHz	10 volts/meter (modulation peak amplitude)

Modulation 30 to 100 percent at 1.0 KHz (square wave)

3.3.4.11.8 Radiated Electric Field Emissions

The HRV shall not produce radiated electric field emissions, both narrowband and broadband, in excess of the limits shown in Figures 3-18 and 3-19. Test method will be in accordance with MIL-STD-462, method RE02.

3.3.4.11.9 Radiated AC Magnetic Field Emissions

The HRV shall not produce radiated alternating current (AC) magnetic field emissions in excess of the limits shown in Figure 3-20. Test method will be in accordance with MIL-STD-462, method RE04.

3.3.4.11.10 Magnetic Induction Field Susceptibility

The HRV shall not experience performance degradation when subjected to the requirements of RS02 as described in MIL-STD-461A/3. This test shall be applied to all standard wire cable bundles interfacing with the HRV. Sixty volts peak shall be used for this test.

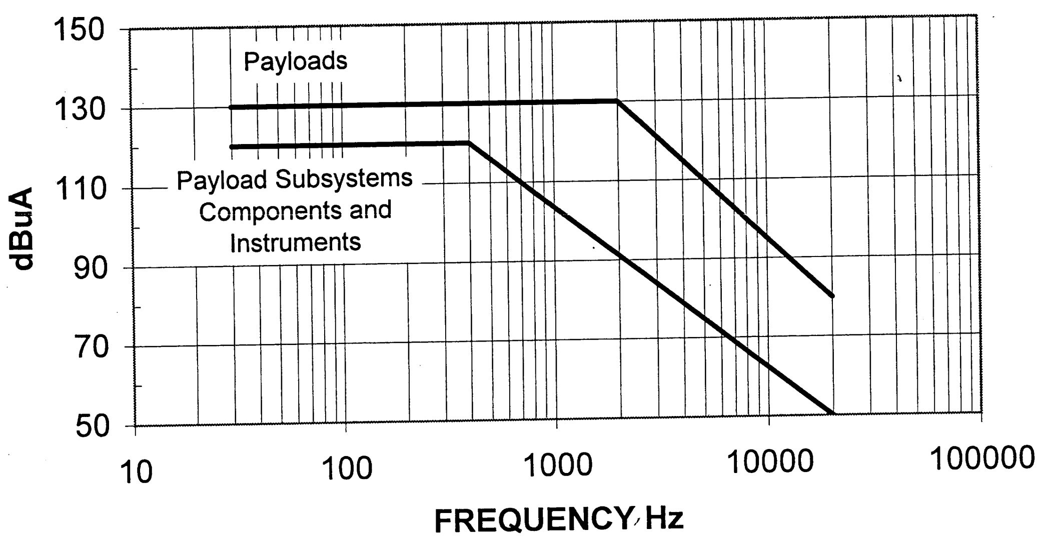


Figure 3-12. CE01 Generated Ripple and Noise Limit

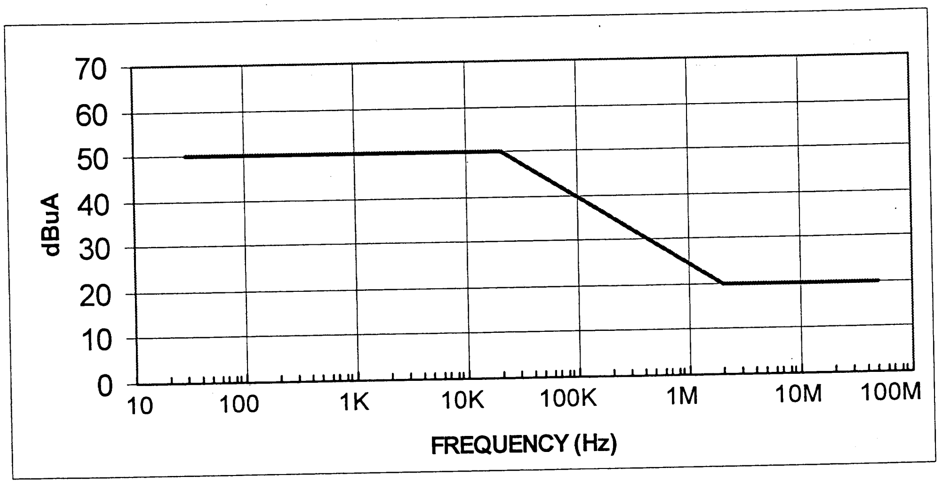


Figure 3-13. Common Mode Generated Ripple and Noise Limit

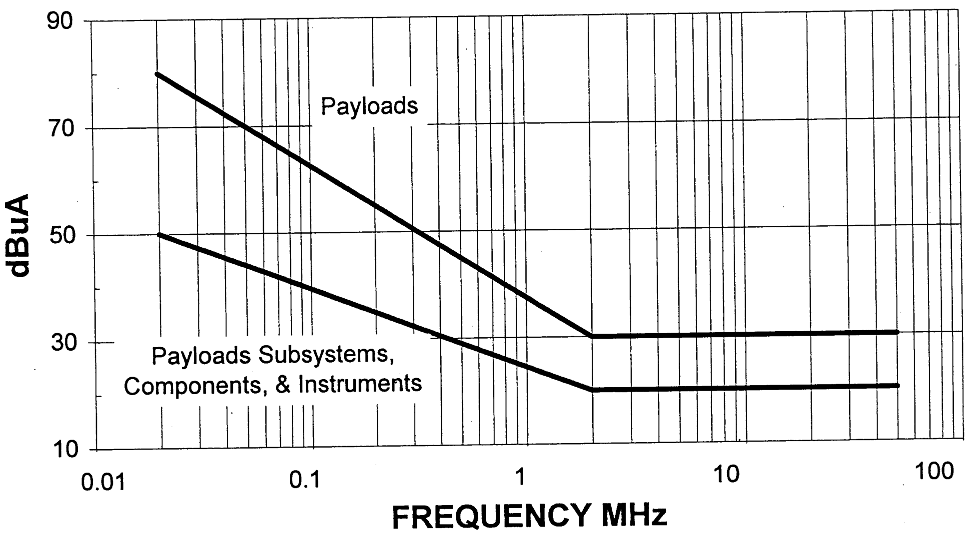


Figure 3-14. CE03 Narrowband Generated Ripple and Noise Limit

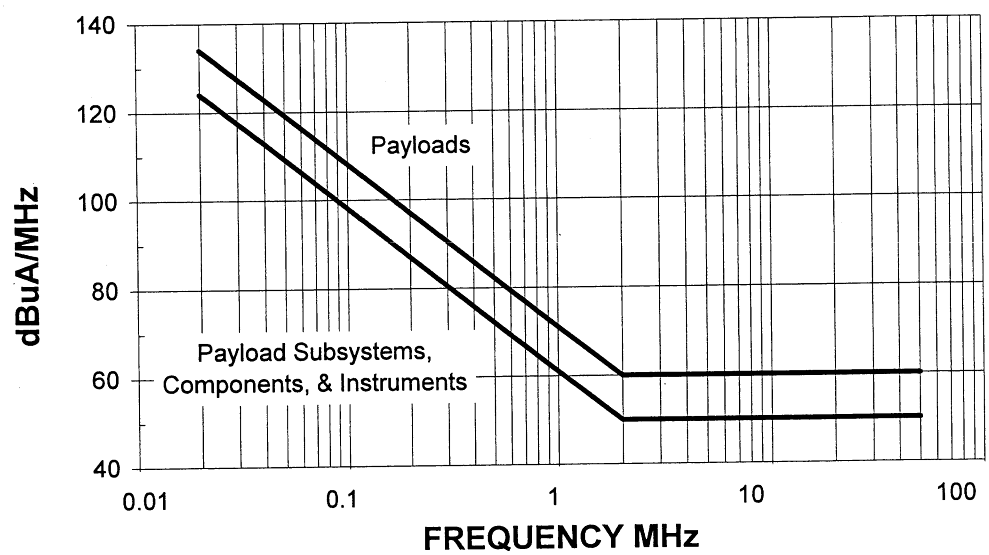


Figure 3-15. CE03 Broadband Generated Ripple and Noise Limit

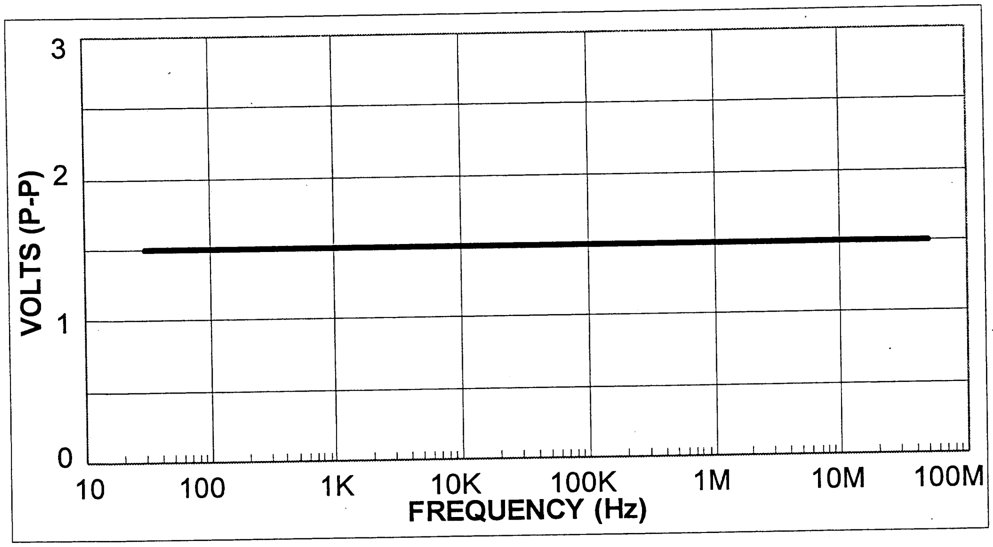


Figure 3-16. CS01/02 Ripple and Noise Susceptibility Limit

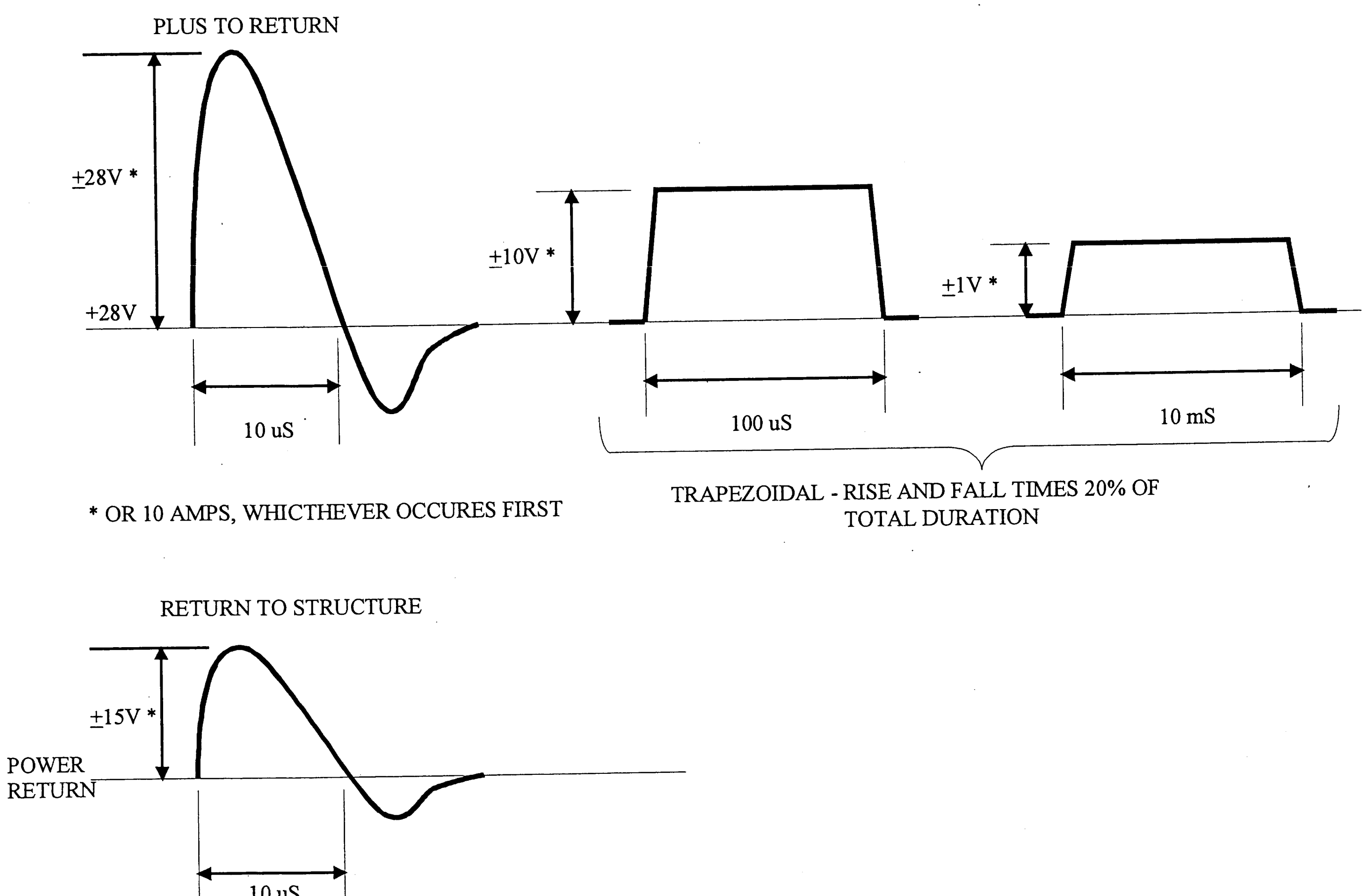


Figure 3-17 CS06 Transient Susceptibility Test Waveforms

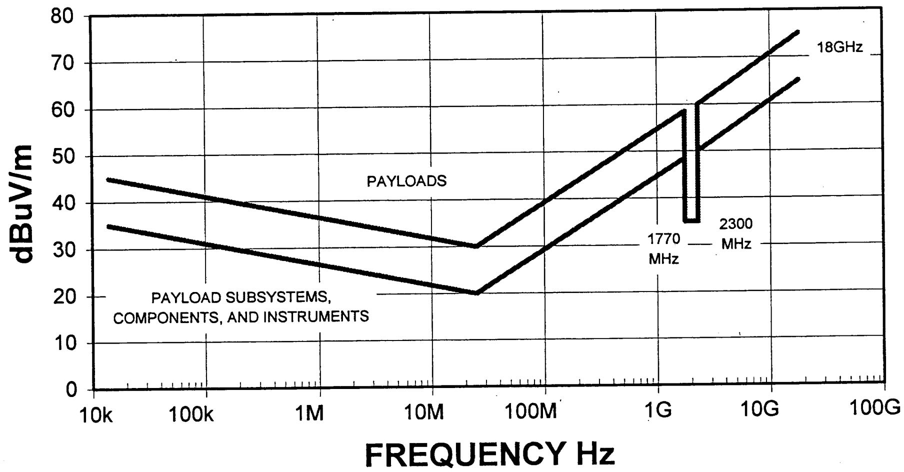


Figure 3-18. RE02 NB Radiated Emissions Test Limit

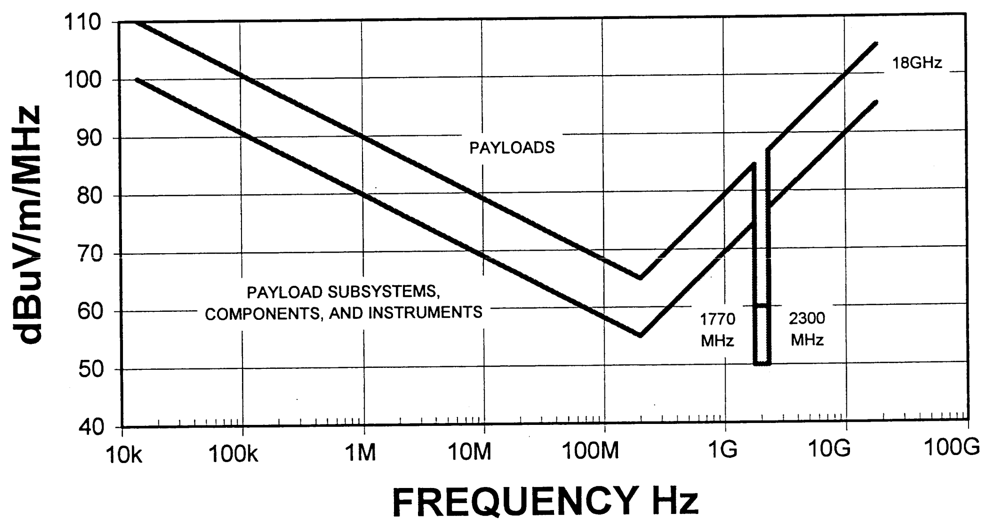


Figure 3-19. RE02 BB Radiated Emissions Test Limit

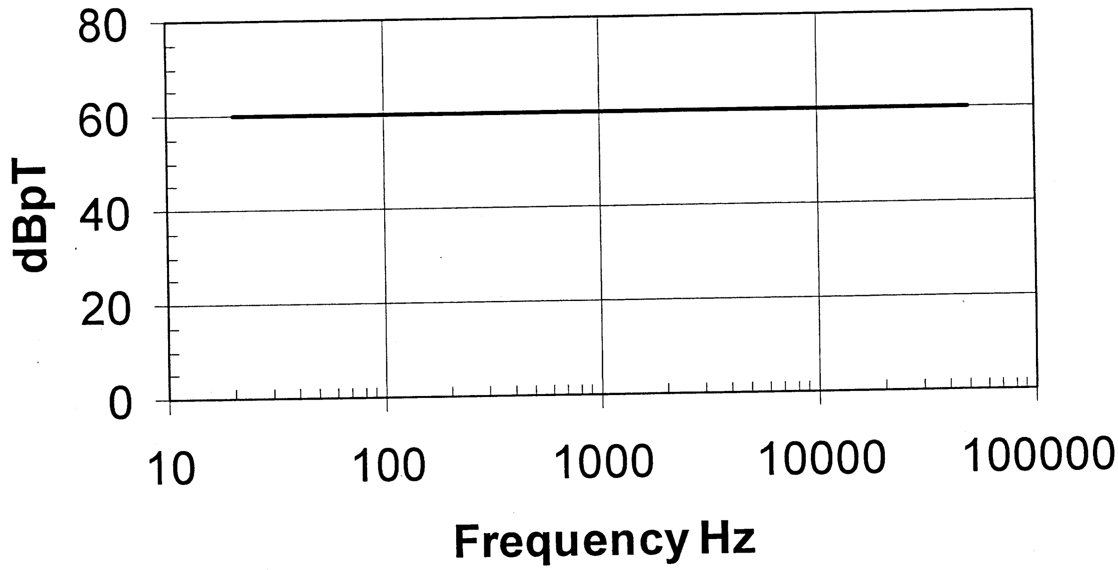


Figure 3-20 RE04 Radiated ac Magnetic Field Emissions Limit

3.3.5 Guidance Navigation and Control

3.3.5.1 HRV Pursuit, Proximity Operations and Docking

HST uncontrolled body rates will yield no additional data to support this HRV mode.

During HST controlled body rate capture, HST ephemeris and rate data will be at least as well as defined in 3.2.1.1.1.

There shall be a minimum of a 25 Km separation below the HST altitude at orbit insertion to protect the HST from any damage.

There shall be Authority to Proceed (ATP) ground commands required prior to initiation of all phases of the mission.

During the capture phase, the HRV shall provide an autonomous abort capability for anomalous operation conditions.
The HRV shall provide a contingency ground abort capability for all autonomous operations.

3.3.5.2 HRV Servicing Operations

The HRV shall provide the combined HST/HRV vehicle control during servicing of the HST.

3.3.5.3 HST Active Control

From time of capture to de-orbit, either HRV or HST GN&C functions shall be active but not both simultaneously.

3.3.5.4 HRV Post Servicing Operation

The HRV shall provide relative GPS navigational sensors for a controlled separation between the DM and the EM post servicing.

3.3.5.5 Video

N/A

3.3.5.6 LIDAR

N/A

3.3.5.7 Propulsion

The HRV shall maintain a minimum of 50m (TBR) safety zone from HST during HST inspection and rate determination.
The HRV shall maintain a minimum of 5m (TBR) safety zone from HST during robot arm deployment and capture.

3.3.6 Instrumentation and Communication Interfaces (TBD)

3.3.6.1 Command Types

3.3.6.2 Command Formats

3.3.6.3 Command Signal Characteristics

3.3.6.4 Differential Signals

3.3.6.5 Data Interface

3.3.6.5.1 Data Functions And Characteristics

3.3.6.5.2 Data Formats And Timing

3.3.6.5.3 Data Transfer Rates

3.3.6.5.4 Data Input Interface

3.3.6.5.5 Timing Interface

3.3.6.6 RF Communication

The HST and HRV communications systems shall be designed as to not mutually interfere with each other. RF communications between the HST and HRV are not required.

3.3.6.7 ECU to 1553 I/O Signal Characteristics

Refer to MIL-STD-1553B.

3.3.7 ERC Interfaces (TBD)

3.3.7.1 Restricted Zones

3.3.7.2 ERC Temporary Stowage

3.3.8 Safety Interfaces

The Safety interface requirements are defined in the General Environmental Verification Specification (GEVS) for STS and ELV Payloads, Subsystems, and Components (GEV-SE) and the Eastern and Western Range (EWR) 127-1 Range Safety Requirements.

3.4 Launch Vehicle to HRV Interfaces

3.5 DM to EM Interfaces

3.5.4.4 Power Buses

The HRV Power Bus(es) shall be sized to carry TBD Amps. The DM and EM Power Buses shall be electrically and mechanically dematable from each other. A capability shall be provided to dead-face power on each side of the DM to EM Power Bus interface(s) prior to mate or demate.

3.6 HRV to Grapple Arm Interfaces

The HRV to Grapple Arm interface shall be compatible with the HRV to Grapple Arm ICD and the Grapple Arm to Dexterous Robot ICD.

3.7 HRV to ORI/ORU and Dexterous Robot Interfaces

Reference ST-ICD-03, ST-ICD-91 (COS Waivers are defined in ST-ICD-02, Section 10.10) and HRV-DR-ICD (TBD). The instrument load and vibration qualifications are provided in documents (TBD).

3.7.2.1 Liftoff Loads

The instrument load and vibration qualifications are provided in documents WFC3 Structural Verification Matrix and COS Structural Verification Matrix (TBD).

3.7.3.1.2 SI to EM Mount Point Conductances

At each of the three attachment points for COS and WFC3 (A, B and C latches) the following conditions are maintained while installed on the EM.

a. The temperature at the EM side of each attachment fitting is within the range of –5°C to +35°C.
b. The maximum effective thermal conductance of each attachment fitting on the EM is as follows:
   Point A Fitting: 0.05 W/°C
   Point B Fitting: 0.08 W/°C
   Point C Fitting: 0.05 W/°C

3.7.3.2.2 SI Internal Fields.

The HRV design shall be compatible with the magnetic fields generated and induced by HST ORU components while subjected to the earth's magnetic field. In addition to the earth's field, the HRV design shall comply with the following magnetic field interfaces.
Axial SI: A/C – Latch: 8 gauss; B-Latch: 16 gauss
Radial SI (TBR): A/B/C – Latches: 6 gauss

4.0 DESIGN REQUIREMENTS (Note: Level III Requirements)

4.1 HRV Design Requirements

4.1.1 MECHANICAL AND STRUCTURAL DESIGN

4.1.1.1 Envelopes

Defined in the Interface Section above.
The static and dynamic envelopes for the HRV shall not exceed the limits of the 5 meter fairings of the Atlas V or Delta 4 ELVs.

4.1.1.2 Stiffness

The first lateral mode of the HRV structure (combined DM/EM) shall be greater than or equal to 10Hz.

4.1.1.3 Relative Deflections

The HRV shall be designed to accommodate the relative deflections imposed at FSS Berthing Pins, which arise from HST thermal and mechanical distortions. For purposes of designing the HRV hardware, the maximum relative deflections of the HST FSS Berthing Pins in the V1 direction is +/- 0.38 inches and V2 or V3 directions are +/- 0.25 inches and shall be considered design condition enforced boundary motions.

4.1.1.4 Loads

4.1.1.4.1 Flight Design Loads

All HRV structural components and enclosures shall be designed to the quasi-static loads shown in Table 4-1 until such time when dynamic coupled loads can be provided. These load factors are weight dependent and act through a component's center of gravity. These load factors are to be applied singularly in each component's orthogonal axis and are intended to envelope mechanically transmitted and acoustically induced random vibration as well as low frequency transients.

Table 4-1 Limit Load Factors for HRV Components (TBR)

Weight (lbs.)	Load Factor (G's)
0 to 20	40
20 to 50	31
50 to 100	22
100 to 200	17
200 to 500	13

4.1.1.4.2 Component Equipment Loads

Design load factors for component equipment, such as electronic boxes, motors, compressors, and similar components, shall comply with the design load requirements defined in Section 4.1.1.4.1 4.1.4.4.1 of this document.

4.1.1.4.3 Component Random Vibration

HRV components shall be tested to levels consistent with ELV qualification levels defined in GEVS-SE. The levels for components weighing less than 50 lbs are shown in Table 2.4-4 Generalized Random Vibration Test levels (STS or ELV) 22.7-Kg (50 lb or less). For components weighing over 50 lbs., the test levels shall be adjusted per the guidelines in Table 2.4-4 of GEVS-SE. These levels may be substituted for random vibration spectrums derived from levels measured at the component mounting locations during previous subsystem or payload testing if this data is not available. After each axis of testing, the component shall be examined for mechanical integrity and functionally tested unless approved by the HST project in advance. Pre and post random vibration sine sweeps shall show no change greater than 10% in frequency and 15% in damping at major modes.

4.1.1.4.4 Acoustic Loads

The HRV assembly hardware shall be subjected to an acoustic test in a reverberant sound pressure field to verify its ability to survive the ELV liftoff acoustic environment and to provide a final workmanship acoustic test.

Test levels for this test shall conform to the ELV users guide (TBD).

4.1.1.4.5 Pressure Differential

Non-pressurized components of the HRV shall be vented to ensure that structural capabilities are not exceeded during launch. Maximum depressurization rates are 0.3 pounds per square inch (psi)/second and 0.76 psi/second.

Maximum pressurization rate is defined in the ELV users guide (TBD). Figure 4-1 provides the component differential pressure versus area to volume ratio. Figure 4-2 provides the ELV depressurization plot (TBR).

4.1.1.4.6 On-Orbit Loads

All components of the HRV, including all flexible connections, shall be designed for on-orbit loads and thermal gradients occurring during installation and operation over the remaining HST lifetime. The derived loads and thermal gradients shall meet limit condition events, as defined in Table 2.4-2 of GEVS-SE. Preliminary design loads for on-orbit events shall be as defined in Table 4-2. These preliminary loads shall be superseded by on-orbit coupled loads analyses based on test verified math models of HRV hardware, covering all planned and contingency HRSDM configurations.

The relative deflections of 4.1.1.3 shall be taken as enforced motions, which must be directly combined with worst-case HRV absolute value thermal and mechanical loads conditions. All values shall act concurrently.

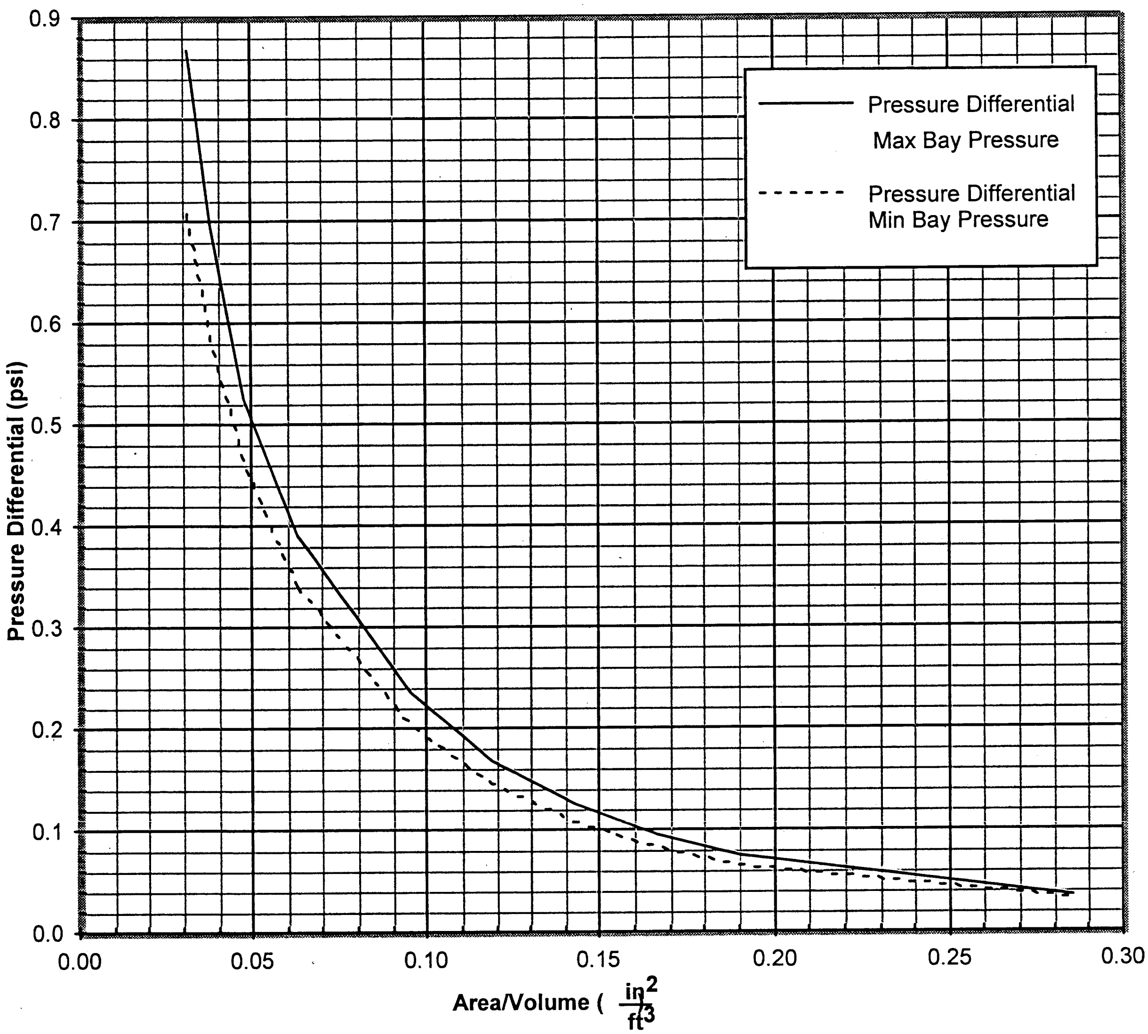


Figure 4-1. Component Differential Pressure (psi) vs Area to Volume Ratio

$$\left(\frac{orificeeffectivearea - in2}{componentvolume - ft3}\right)$$

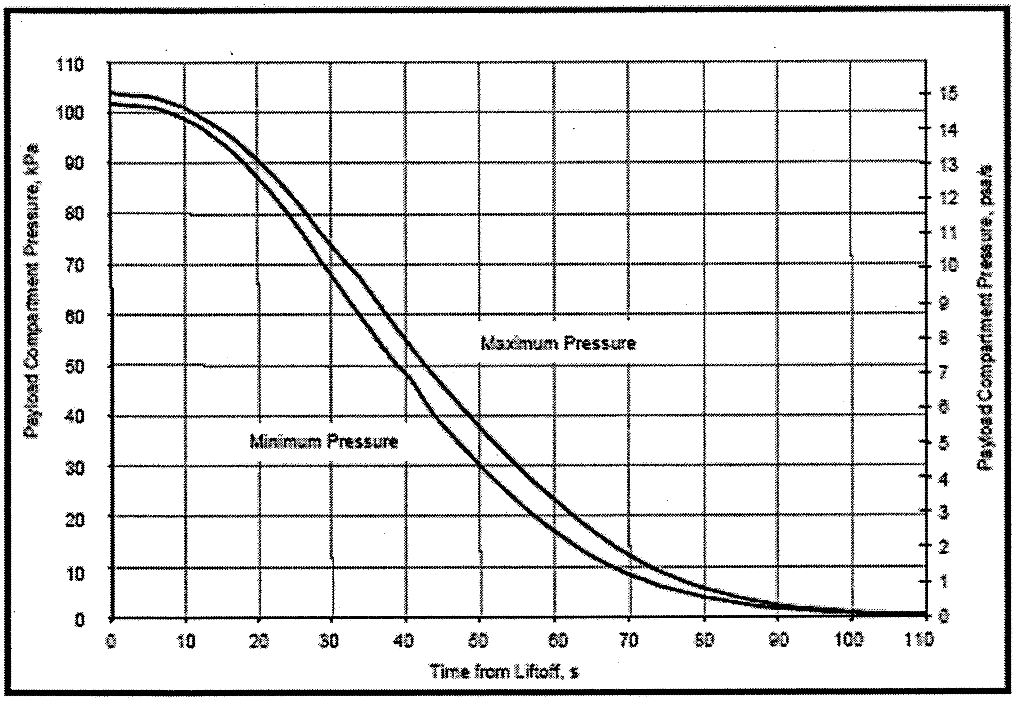


Figure 3.2.6-5 Typical Static Pressure Profiles Inside the 5-m Fairing

Figure 4-2 ELV depressurization plots. (TBR)

Table 4-2
On-Orbit Preliminary Design Loads for HRV

Condition	Limit Condition Load	Notes
Robotic Operations	Servicing force of 100 lbs. and concurrent moment of 75 in-lbs., both as static equivalent loads	1,2
Installed, during HRSDM	Input base motion as a 0.25 G static equivalent force Direct pressure impingement as a 0.002 milli psi rectangular half pulse of 0.04 ≤ duration ≤ 1.0 sec	2 3

Notes:
1. To be applied at any design handhold or grapple fixture and reacted two different ways. In one case, load is reacted only inertially. In second case, load is reacted by any opposing direction reactions applied at any other design handhold. All such combinations shall be considered.
2. Shall be applied in any direction and assumed to be a limit condition when combined with limit condition on-orbit derived thermal gradients.

3. This case is applicable only if the component is located exterior to the SSM.

4.1.1.4.7 On-Orbit Installation Loads

Defined in the Interface Section above.

For compatibility with HST strength capability (TBR), shall be designed not to impart a limit load greater than 100 lbs(any standoff can take 300#, FOS=3.0). to any one HST handrail. Note that this constraint applies to any one multi-span handrail and its associated support standoff to the SSM.

If the HST PFR sockets are to be used for securing HRV components to the HST, then loads imparted during installation and operation shall be compatible with the defined limit load capability of these sockets. These limit loads are defined below in Table 4-3.

Table 4-3 (TBR)

HST PFR Limit Load Capability*

Fx (lbs.)	Fy (lbs.)	Fz (lbs.)	Mx (inch-lbs.)	My (inch-lbs.)	Mz (inch-lbs.)
60	50	135	1650	1400	1100

*Loads are based on PFR analyses that apply loads at the PFR platform in the local PFR axes(Ref: EM FS&S 989, "SM-2 HST PFR Worksite Capability Assessment")

4.1.1.4.8 ERC Loads

All HRV components and systems shall be designed to withstand robotic induced loading of (TBD) forces and (TBD) moments at any ERC interface and in any direction. These loads shall be assumed to be a static equivalent force applied, and can occur at any time during the installation.

4.1.1.4.9 Ground Transportation Loads

Whether stowed on its GSE or packaged in its shipping container(s) the HRV shall be subjected to loads no higher than those given in Sections 4.1.1.4.1 and 4.1.1.4.2 of this document during all ground handling and transport.

4.1.1.5 Design Factors

4.1.1.5.1 Factors of Safety - Non-pressurized Components

The HRV structural elements shall be designed using factors of safety that comply with GEVS-SE. For tested components, an ultimate factor of safety equal to 1.4 and a yield factor of safety equal to 1.25 shall be used. For untested components, an ultimate factor of safety equal to 2.6 and a yield factor of safety equal to 2.0 shall be used.

4.1.1.5.2 **Factor of Safety** - Pressurized Components

Heatpipe components, which use ammonia as a working fluid, shall be analyzed using minimum factors of safety of 1.5 on yield and 2.5 on ultimate for the maximum design pressure. All pressurized components shall comply with MIL-STD-1522 (TBR).

4.1.1.6 Strength

HRV shall be designed and analyzed using the "A" Values of MIL-HDBK-5. The system shall also be designed to withstand, simultaneously, the limit loads and other accompanying environmental effects for each design condition, without experiencing plastic deformation, which would limit the performance of any on-orbit functions or be in excess of that defined as yield by either of the above sources.

4.1.1.7 Fracture Control

A Fracture Control program in accordance with NASA-STD-5003 shall be developed in order to ensure mission success. Items which require fracture control analysis include:

a. Pressure vessels, dewars, lines, and fittings (per NHB-8071.1),
b. Castings (unless hot isostatically pressed and the flight article is proof tested to 1.25 times limit load),
c. Weldments,
d. Parts made of materials on Tables II or III of MSFC-SPEC-522B if under sustained tensile stress. (Note: All structural applications of these materials requires that a Materials Usage Agreement (MUA) must be negotiated with the project office: refer
e. Parts made of materials susceptible to cracking during quenching,
f. Nonredundant, mission-critical preloaded springs loaded to greater than 25 percent of ultimate strength.

All glass elements, that are stressed above 10% of their ultimate tensile strength, shall also be shown by fracture analysis to satisfy "Safe-life" or "Fail-safe" conditions or be subjected to a proof loads test at 1.0 times limit level.

This analysis shall be performed on the HRV that demonstrates the hardware will survive one mission lifetime (with a scatter factor of four) with a nominal launch. A loading spectrum shall be developed that includes all transportation, handling, and test loads, as well as a nominal launch and any thermally induced on-orbit cycles.

4.1.1.8 Fasteners

Fasteners shall meet the requirements of GSFC S-313-100.

4.1.1.9 Weight

The weight of the HRV subsystem hardware, not including ELV hardware, shall be less than or equal to the allocations in Table 4-4. The DM to EM separation mechanism shall be accounted for in the EM weight allocation. The center of gravity, moments and products of inertia of the De-orbit and Ejection Modules shall be mathematically calculated. The final weight and center of gravity of each module shall be test-measured in two axes. This measurement shall be documented according to the HRV Mass Properties Control Plan, SMR-5091 (TBD).

A detailed mass properties tracking and reporting system shall be implemented and kept current during the design and fabrication phases in accordance with SMR-5091 (TBD).

Table 4-4

HRV Weight Allocations[1]

Subsystem	De-orbit Module (lbs)	Ejection Module (lbs)	Total Weight Allocation (lbs)
Total	7500	17000	24500

4.1.1.10 Pointing Control, Stability and Jitter

4.1.1.10.1 HRV Combined HRV/HST Stability

The HRV/HST, collectively, shall meet the dynamic performance requirements defined in terms of the modal gains, Kb, for the HRV fixed based modes. For the modes above 2 Hz., the root sum square of the modal gains in the frequency band 0.8 fo to 1.2 fo when plotted about any center frequency, fo Hz., shall be less than the maximum Kb as defined in Section 3.2.4.2 of this document.

The modal gain Kb for the DM attached to a central rigid body HST is defined as:

Kb = (theta)v2 X I)

m

where (theta) v is the modal slope of the central rigid body, I is the moment of inertia, and m is the modal mass.

The moment of inertia of the central rigid body, HST, is defined in Section 3.3.1.15.1 of this document.

4.1.1.10.2 HRV Jitter Disturbance

The HRV shall be designed and verified to not exceed the maximum allowable interface disturbances defined in Section 3.2.4.3 of this document for science performance.

4.1.1.10.2.1 Friction Factor of Safety

To eliminate new sources of on-orbit jitter disturbances, the HRV hardware and interface mechanisms shall be designed to eliminate details that may slip or stick during on-orbit free flight operations to the maximum extent practical. Where these slip or stick details cannot be eliminated, such detail shall be designed and demonstrated through testing to have a factor of 4.0 between the maximum derived applied load at the details for all on-orbit free flight conditions, and the minimum load which causes slip as demonstrated by testing.

4.1.1.10.2.2 HRV Interface Torques

Maximum torque at the interface shall be as defined in Section 3.2.4.3 of this document.

4.1.1.11 ERC Accommodations

4.1.1.11.1 ERC Interfaces

HRV shall have ERC handling interfaces to allow ORU/ORI retrieval from the stowed position.

4.1.1.11.1.1 HRV Connector Support Bracket(s)

The HRV shall provide an electrical interface bracket(s) that is of rack and panel design similar to GSFC drawing GD 2033311, Harness and Bracket Assembly, Data (W).

This panel(s) shall include the connectors for the ECU to RSU Interfaces (3), the DM Battery to SA3 Diode Box interfaces (4), the DM computer to HST486 1553 interface (1) and the DM Battery to the NCS power augmentation interface (TBD).

The support structure shall be designed to provide access to the rack and panel Connector Brackets.

4.1.1.11.1.2 ERC Handling Interfaces

All interfaces shall be designed to allow access for the intended robotic operation.

All electrical connectors shall be protected against inadvertent damage and gross contamination.

4.1.1.11.1.3 Attachment/Operating Interfaces

The HRV design must accommodate the following attachment and operating interface criteria:

a. All ERC attachment and operating interfaces shall be reversible.
b. All attachment and operating interfaces shall include instructional labels indicating the proper direction, turns, alignment, and torque necessary for actuation (TBR).
c. All attachment and operating interfaces shall protect against accidental activation/deactivation (for example, locking features, pre-load, or covers) (TBR).
d. The HRV ERC interfaces shall not have any loose items (i.e. all bolts, nuts, etc. shall be captive).

4.1.1.12 Mechanisms

All HRV mechanisms shall meet the design requirements of EM: FS&S 1483.

4.1.2 ELECTRICAL DESIGN

The HRV component electrical design shall be compatible with existing HST power and data systems.

4.1.2.1 Interfaces

Defined in Sections 3.3, 3.4 and 3.5.

4.1.2.2 Electrical Power

Defined in Section 3.3.4.

4.1.2.2.1 Electrical Power for Servicing

The DM and EM SA shall provide a minimum load capability of 3263 + 150 (**TBR**) Watts to support robotics operation and SI thermal requirements during servicing.

4.1.2.2.2 Dexterous Robot Voltage

The HRV shall provide 120 Vdc service for the dexterous robot. The maximum power drawn by the dexterous robot shall be 2000 Watts.

4.1.2.2.3 Electrical Power Telemetry

Independent current telemetry for all external vehicle power feeds shall be provided.

4.1.2.3 Networks

The wiring installation will consist primarily of cable harnesses. The wire used in cable harnesses shall conform to MIL-C-17, MIL-W-22759, or MIL-W-81381. Connectors shall comply with MIL-C-38999 or MIL-C-39012. Electrical connectors using crimped connections shall be in accordance with NHB 5300.4 (3H). Brazing shall be in accordance with Specification MIL-B-7883, and soldering shall be in accordance with NHB 5300.4 (3A-1). Printed circuits shall comply with NHB 5300.4 (3I) or other GSFC approved contractor specifications. Conformal coating shall be in accordance with NHB 5300.4 (3J). When redundant paths are provided in the cabling, they shall be routed through separate connectors to the extent practical. The insulation resistance between each conductor and shields, and between each conductor and connector shell, shall be at least 1 megaohm at an applied potential of 500 Volts Direct Current (Vdc).

Electrical wiring harness assemblies shall be in accordance with NHB 5300.4 (3G). Protective circuitry and wire sizing shall be in accordance with PPL-21 to ensure the safe and reliable operation of the electrical system and prevent fault propagation and damage. Analog circuits, such as those used on thermistors, which require remote signal conditioning, shall be routed on a twisted shielded pair and shall not use structure as a return. Twisted wire pairs shall conform to MIL-C-27500.

4.1.2.4 Grounding

The HRV primary DC power returns shall be isolated from structure by a minimum resistance of one megaohm. Component case grounds shall comply with MIL-B-5087, class R bonding.

4.1.2.5 Electrical, Electronic and Electromechanical (EEE) Parts

The EEE parts shall be selected in accordance with the requirements of GSFC-PPL-21 and MIL-STD-975. The requirements of these documents provide for the maximum use of the National Aeronautics and Space Administration (NASA) Standard Parts Program. These parts are grade 2, but either grade 1 or grade 2 parts may be used. Standard parts shall be procured in accordance with the requirements of GSFC PPL-21 (Ref. MIL-H-38534).

4.1.2.6 Corona Suppression

Electrical and electronic subsystems shall be designed so that their performance will not be impaired by coronal discharge. They also shall not be a source of interference that could adversely affect the operation of other equipment.
Where adverse coronal effects are avoided by pressurizing or evacuating a component, the seals shall be capable of maintaining the required internal pressure throughout the life of the hardware. Where adverse coronal effects are avoided by restricting operation to space vacuum conditions, the equipment shall be capable of reaching the required vacuum level of 10-5 torr within 10 hours.

4.1.2.7 Electromagnetic Compatibility (EMC)

Electromagnetic emissions of the HRV and associated avionics shall not degrade the performance of any HST SI. Attachment of the HRV hardware to the in-orbit SIs shall not result in additional electronic noise in the SI detectors. The HRV shall comply with the requirements of the GEVS-SE. The requirements specified in Table 4-5 shall apply.

The HRV shall comply with the requirements of the GEVS-SE for the 120 Vdc power supply to the robot (TBD).

4.1.2.7.1 Radiated Susceptibility (E-Field, RS-03) (Peak field Strengths)

The HRV shall not experience performance degradation when subjected to the following radiated fields:

14 KHz to 35 MHz	2 volt/meter CW (continuous wave)
35 MHz to 2 GHz	2 volt/meter AM (modulation peak amplitude)
2GHz to 12 GHz	5 volts/meter AM (modulation peak amplitude)
12 GHz to 18 GHz	10 volts/meter (modulation peak amplitude)

Modulation 30 to 100 percent at 1.0 KHz (square wave)

Table 4-5
Applicable GEVS EMC Requirements

Requirement	Designation	GEVS Paragraph
Conducted Emissions	CE01, DC Power Lines	2.5.2.1 a & b
Conducted Emissions	CE03 DC Power Lines	2.5.2.1 a, b & c
Radiated Emissions	RE02 Electric Field	2.5.2.2 c, d & e
Radiated Emissions	RE04 Magnetic Fields	2.5.2.2 b
Conducted Susceptibility	CSO1 DC Power Lines	2.5.3.1 a
Conducted Susceptibility	CS02 DC Power Lines	2.5.3.1 a
Conducted Susceptibility	CS06 Transient, DC Power Lines	2.5.3.1 e

4.1.2.7.2 In-Rush Current

In-rush current rise and fall times shall be limited to less than 6 amps/microsecond.

4.1.2.7.3 Magnetic Induction Field Susceptibility (RS02)

The HRV shall not experience performance degradation when subjected to the requirements of RS02 as described in MIL-STD-461A/3. This test shall be applied to all standard wire cable bundles interfacing with the HRV. Sixty volts peak shall be used for this test.

4.1.2.8 Circuit Protection and Fault Isolation

The HRV design shall incorporate fault protection to isolate electrical shorts occurring within the HRV equipment per EEE-INST-002. Circuit protection shall be sized to ensure that faults are isolated downstream of the power bus(es).

4.1.2.9 Workmanship

Workmanship standards shall be in accordance with the requirements listed below, or GSFC approved contractor documentation.

- Conformal Coating and Staking: NASA-STD-8739.1
- Soldering – Flight Surface Mount Technology: NASA-STD-8739.2
- Soldering – Flight, Manual (Hand): NASA-STD-8739.3
- Crimping, Wiring and Harnessing: NASA-STD-8739.4
- Printed Wiring Board (PWB) Design: Space flight PWB designs shall be per the specifications listed below and shall not include features that prevent the finished boards from complying with Class 3 Requirements of the appropriate manufacturing standards as listed below.
    - IPC-2221, Generic Standard on Printed Board Design
    - IPC-2222, Sectional Design Standard for Rigid Organic Printed Boards
    - IPC-2223, Sectional Design Standard for Flexible Printed Boards
- Printed Wiring Board Manufacture (flight): PWB shall be manufactured in accordance with Class 3 requirements of the PWB manufacturing standards referenced below. The contractor shall provide PWB coupons to the GSFC Materials Engineering Branch (MEB) for a

GSFC/MEB approved laboratory for evaluation. Approval shall be obtained prior to population of flight PWBs. Coupons and test reports are not required for delivery to GSFC/MEB if the contractor has the coupons evaluated by a laboratory that ahs been approved by the GSFC/MEB, however they shall be retained and included as part of the Project's documentation/data deliverables package. NOTE: When approved by the GSFC Project Office, the contractor may use MIL-P-55110, Revision E , as an alternative to the above referenced PWB manufacturing standards (note that this is not the current version, revisions F and later are not recommended for flight hardware).

- IPC A-600, Acceptability of Printed Boards
- IPC-6011, Generic Performance Specification for Printed Boards.
- IPC-6012, Qualification and Performance Specification for Rigid Printed Boards
- IPC-6013, Qualification and Performance Specification for Flexible Printed Boards
- MIL-P-55110E, Printed Wiring Board, Rigid, General Specification for

4.1.3 Thermal

HST Thermal Interfaces, including conductance, are defined in Section 3.3.3.1.

4.1.3.1 Conduction

There shall be minimal conductive coupling between the De-orbit Module and the Ejection Module. The conductive transfer of heat between the DM and EM shall be less than 10 watts (TBR).

4.1.3.2 Radiation

There should be minimal radiative coupling between the De-orbit Module and the Ejection Module. The radiative heat transfer between the DM and the EM shall be less than 5 watts.

4.1.3.3 Temperature Range

Table 4-6 defines the SI temperature limits for different mission phases. The replacement SI shall be maintained within the initial transport limits in a solar oriented +V3 sun pointing attitude for a minimum of 12 hours (TBD) before expected transport. For other mission phases and for the returning SI the EM shall not exceed the non-operational (red) limits. If these limits are exceeded, SI damage could occur and operational performance could be degraded.

Table 4-6 SI Limits for Mission Phases (°C)

	WFPC II	WFC3	COS	COSTAR
Initial Transport	N/A	20	20	N/A
Non-Operational	-30 to 40	-30 to 40	-10 to +35	-10 to +35
Structural Safety	-40 to 40	-30 to 55	-55 to +60	-55 to +60

The ERC Tools shall be able to survive and operate in a –100°C to +100°C (TBR) environment.

4.1.3.4 Surface Properties

Interface defined in section above.

Active Thermal Control

Active thermal control employed on the De-orbit Module or Ejection Module shall be redundant and testable in a 1-G environment.
Thermal control heaters shall be controlled by the HRV, and shall be thermally sized for the entire operational bus voltage range. The survival heaters shall be sized for the minimum survival bus voltage range.

In order to ensure proper operation of heat pipes on DM and EM, the rotational rate of the HRV shall be no more than 2.6°/sec.

Thermal Environment

The Thermal Environment that shall be used for analysis is as follows:
Solar Constant: 1419 W/m^2 (Hot) and 1287 W/m^2 (Cold)
Albedo: 0.35 (Hot) and 0.25 (Cold)
Earth IR: 265 W/m^2 (Hot) and 208 W/m^2 (Cold)

4.1.4 Guidance Navigation and Control

The HRV shall perform all guidance, navigation, and control functions for the combined HRV.

4.1.4.1 Attitude Control System

The HRV shall be capable of initial attitude determination after launch vehicle separation. The rate null shall be accomplished within 100 min (TBR). The HRV shall provide all necessary vehicle control modes to pursue, capture, dock, service, and de-orbit the HST. These include control modes which enable solar power generation, thermal stability, orbit maneuvers, momentum management, HST acquisition and tracking, HST capture, HST rate null, and safe hold. During the science operations phase, the HRV control system will be inactive.

4.1.4.2 Navigation

The HRV shall provide all absolute and relative navigation capability to support the pursuit, capture, docking of HST. The HRV shall support on-board absolute and relative navigation. The HRV navigation system shall also support servicing and de-orbit by providing absolute navigation. The HRV navigation system will be inactive during the science operations phase.

If HST onboard attitude determination is functional, it will be made available to the HRV relative navigation system through the ground system.

4.1.4.3 Maneuver Control

The HRV control system shall be capable of executing ground up-linked maneuver commands during the pursuit and proximity operations phase. The HRV shall be capable of on-board maneuver planning and execution during the proximity operations and capture. The transition from ground-based maneuver planning to on-board maneuver planning will occur during proximity operations. All de-orbit maneuvers will be planned from the ground.

4.1.4.4 Propulsion

The Propulsion System shall be compatible with HST contamination requirements defined in STR-29. If mono-prop is chosen, hydrazine shall be ultra-pure grade.

4.1.5 Communications

The HRV shall provide forward and return link communications between the control center and the HRV through the Space Network (TDRSS) and the Ground Network (DSN and GSTDN). The HRV command link shall utilize authentication and/or encryption for commands that could jeopardize the mission.

Real-time video transmission through the HGAs to the TDRSS shall be provided by the HRV. The EM HGA system shall be capable of tracking up to four TDRSS satellites during pursuit, docking, and servicing operations. The HGA masts shall be aligned to the HST V3 axis to minimize blockage due to the HST and HRV solar array planes. The HRV shall provide bit error rates of less than 1 x 10^{-5} bits/sec and link margins of greater than +3 dB.

4.1.6 Pyrotechnic

4.1.7 Materials

4.1.7.1 Materials and Processes

Materials and processes shall be in accordance with SMR-5000. In order to anticipate and minimize materials problems during space hardware development and operation, when selecting materials and lubricants, the developer shall consider potential problem areas such as radiation effects, thermal cycling, stress corrosion cracking, galvanic corrosion, hydrogen embrittlement, lubrication, contamination of cooled surfaces, composite materials, atomic oxygen, useful life, vacuum outgassing, toxic offgassing, flammability and fracture toughness, as well as the properties required by each material usage or application.
A Materials List shall be submitted for approval.

4.1.7.2 Corrosion of Metal Parts

Metal parts shall be protected from corrosion by stress-reliev-ing, plating, anodizing, chemical coatings, organic finishes, or combinations thereof. Such protection shall be compatible with the contamination constraints and operating/space environmental requirements. Applications involving dissimilar metals shall be evaluated to assure that galvanic corrosion is minimized.

4.1.7.3 Material Outgassing

The outgassing of organic materials used in the HRV shall meet the requirements of STR-29. . Lubricants shall have a vapor pressure <= 10-7 Torr at +40 C (TBR).

Use of silicones shall be restricted to less than 1 kg of material and may only be used in areas with no direct line of sight to the HST.

4.1.7.4 Castings

Castings shall not be used in the design without the prior consent of the GSFC Materials Assurance Engineer.

4.1.8 NATURAL ENVIRONMENT

The HRV shall be designed for the natural environments of NASA TMX-73331.

4.1.8.1 Meteoroid Impact

The HRV shall be designed to minimize the effect of micro-meteoroid impingement. External components shall be analyzed using the meteoroid flux model defined in NASA TMX-73331.

4.1.8.2 Radiation

All electronic components shall be selected and/or shielded to minimize the potential impact of ionizing radiation, including Single Event Upsets (SEU). Components shall be capable of operating through mission life within specification after exposure to levels specified in **Section 3.3.3.4** over de-orbit life. This requirement may be fulfilled through device tolerances and/or additional shielding.

4.1.8.3 Atomic Oxygen

The design of critical external surfaces of the HRV shall take into consideration the atomic oxygen environment of the HST orbit. Reference TMX 73331.

The HRV shall not lose functionality due to AO exposure at HST orbital altitudes nor due to combined exposure with other environmental factors over the de-orbit lifetime defined in Section 3.2.2.2.

4.1.9 SAFETY

The HRV shall conform to the safety requirements of the Eastern and Western Range (EWR) 127-1 Range Safety Requirements.

4.1.9.1 Hazardous Materials

All components of the HRV exposed to hazardous fluids shall meet the fluid compatibility requirements of Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.10 Hazardous Materials.

4.1.9.1.1 Test Requirements

Toxcity, reactivity, compatibility, flammability and/or combustibility testing requirements shall be determined by Range Safety on a case-by-case basis.

4.1.9.2 Range Operations Safety

Operations Safety General Design Requirements are defined in the Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.5, Operations Safety Console.

4.1.9.3 Electrical System Safety

Electrical systems shall comply with Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.14, Electrical and Electronic Equipment.

4.1.9.3.1 Connector Protection

Connectors shall be protected per the Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.14.1.3, EGSE and Flight Hardware Connectors.

4.1.9.4 Ionizing Radiation

Ionizing Radiation flight hardware sources shall comply with Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.9, Radioactive (Ionizing Radiation) Sources.

4.1.9.5 Pressurized Systems and Structures

HRV flight Hardware pressure systems and pressurized structures shall comply with Eastern and Western Range (EWR) 127-1 Range Safety Requirements, Chapter 3.12, Flight Hardware Pressure Systems and Pressurized Structures.

4.1.10 CONTAMINATION

4.1.10.1 Instrument Stowage

The HRV shall comply with the SSE requirements in STR-29 in addition to the requirements listed herein.

4.1.10.1.1 Venting

Vented portions of the structure shall be designed to vent away from HST.

4.1.10.1.2 Surface Cleanliness

All exterior surfaces shall be Visibly Clean Highly Sensitive. Enclosures for aft shroud hardware shall have an interior cleanliness of Level 400B per MIL-STD-1246.

4.1.10.1.3 Particulate Generation

HRV shall be designed to minimize particulate generation during all mission phases. MLI shall be free of particle shedding material.

4.1.10.1.4 Hardware Integration

HRV integration shall be performed in a class 100,000 or better cleanroom. Sub-assembly shall be cleaned prior to their becoming accessible as described in STR-29.

4.1.11 RELIABILITY

The reliability of the HRV design shall ensure that failure modes within the systems shall not propagate to other systems. The HRV shall provide better than 97% reliability, after orbit insertion, for achieving controlled re-entry for the HST/DM combined spacecraft.

4.1.11.1 Fault Tolerance

The HRV design shall be redundant for all mission objectives. The HRV design shall preclude single point failures. The DM to EM separation mechanism shall be two fault tolerant for separation.

4.1.12 LIFE

At the HST EOM the HRV total life (shelf life + useful life) shall satisfy all of its performance requirements.

4.1.12.1 Shelf Life

The HRV shall be designed for a two year lifetime after delivery and before launch without any impact to performance.

4.1.12.2 HRV Life

The HRV shall be designed for a science mission life per Section 3.2.4.4.
The HRV shall be designed to safely de-orbit the HST through de-orbit life per Section 3.2.2.2.

4.1.13 Ground Handling

The HRV shall be capable of being handled in any orientation. All handling fixtures required to be used at KSC shall be certified per EWR 127-1 and supplied with the flight hardware. Ground Handling Equipment and processes used at GSFC shall be in accordance with the Mechanical Systems Center Safety Manual, 540-PG-8715.1.1.

Factory lift equipment shall conform to NASA Standard for Lift Devices and Equipment, doc. no. NASA-STD-8719.9.

4.1.14 Storage and Shipping

The HRV shall be designed for storage in environments listed in Section 3.3.3.7 of this document.

A suitable storage/shipping container shall be designed to permit the system to be stored and shipped via normal commercial transportation systems.

The HRV shall protect for the capability to be air transported and shall conform to the airworthy quasi-static G-factors and conditions described for the C-5A in MIL-STD-1791. HRV equipment and associated component shipping shall conform to Requirements for Packaging, Handling and Transportation for Aeronautical and Space Systems' Equipment and Associated Components, NPR 6000.1E. The environment experienced during shipping or storage shall not exceed the limits of Sections 4.1.3 and 4.1.4 of this document.

4.1.15 Identification and Marking

A parts identification and marking system shall be maintained. Each piece part, including flight spares and test items, shall be identified by a serial number. Parts lists shall be maintained at all subassembly and assembly levels to provide traceability.

Other markings to facilitate integration and testing shall be incorporated on the flight hardware as required.

4.1.16 Documentation

All HRV engineering documentation (including drawings) shall be prepared, approved, released, and changed in accordance with SCM-1020.

4.1.17 Spacecraft Modeling

The De-orbit and Ejection Module designers shall provide analysis reports and reduced math models for both thermal and dynamic.

4.1.17.1 Structural Math Models

The structural models provided by HRV Contractors to the HST Project shall be derived from detailed models used by HRV Contractors in the design, development, and verification of HRV components. The first lateral and torsion modes determined from these simplified models shall agree within ± 3%, with those predicted by the more detailed models. Agreement is determined by comparing natural frequency and modal effective weight properties.

The derived models shall be dynamically reduced to Craig-Bampton (or equivalent) form of up to 600 degrees of freedom for each major HRV component. Transformation matrices shall be included to allow for recovery of critical physical responses in the component, as well as to allow for application of applied loads, pressures, and temperatures for system level assessment. The model must be able to predict motion of major mass items and points of mechanical disturbance. The reduced model shall represent modes below 200 Hz. Data shall be transmitted by electronic media using mutually agreed upon media and format.
In addition, the output data from the detailed model shall be supplied for comparison to the simplified model output data.

4.1.17.2 Thermal Math Models

The HRV thermal models provided by Contractors to the HST Project shall be simplified representations of the detailed models used by HRV Contractors in the design, development, and performance analysis of the HRV.

The simplified thermal models shall be in SINDA format and shall consist of a maximum of 50 nodes, including one node for each of the attachment point interfaces. The models shall be transmitted with a listing of the bulk data, a nodal schematic, and a sample analysis output. Temperature dependent functions such as heaters, louvers, etc., shall be clearly indicated. The model represents all power modes.

In addition, the output data from the more detailed model shall be supplied for comparison to the simplified model data.
The thermal model shall predict the surface temperatures of the HRV within 5°C of the HRV's thermal balance test. The model shall be delivered as a Thermal Synthesizer System (TSS) Geometric model with the conductive and radiative models in SINDA format. Sufficient documentation and figures of the model shall be provided for independent analysis runs.

4.1.18 Ground Handling Interfaces

MGSE (Mechanical Ground Support Equipment) and processes used at GSFC shall be in accordance with the Mechanical Systems Center Safety Manual, 540-PG-8715.1.1.

Lift equipment shall conform to NASA Standard for Lift Devices and Equipment, doc. no. NASA-STD-8719.9.

As a minimum, EGSE shall consist of a selected combination of unmodified COTS components conforming to NFPA 70, UL, and CSA certifications, and custom fabricated equipment conforming to NASA-STD-5005. Any EGSE directly interfacing the flight equipment on HRV shall have been verified as safe-to-mate prior to the application of power. Connector savers shall be used unless written rationale is provided.

4.1.19 Technology Readiness Level

All HRV components shall be TRL 6 or greater; as defined in Mankins, John C., Technology Readiness Levels, White Paper, 06 Apr 1995; by mission Preliminary Design Review (PDR).

4.2 DM Design Requirements

Refer to Section 6.0 for DM requirements.

4.3 EM DESIGN REQUIREMENTS (TBD)

4.3.3.3 EM De-orbit
All flight elements of the HRV shall be consistent with NPD 8710.3.

4.4 GRAPPLE ARM DESIGN REQUIREMENTS (TBD)

Interfaces are defined in HRV-GA-ICD.

5.0 Flight Software

5.1 General Requirements

All flight software (FSW) programs and data for the HRV shall meet the requirements below.

The software component of firmware, consisting of computer programs and data loaded into a class of memory not dynamically modifiable by the computer during processing (e.g., Programmable Read-Only Memories (PROMs), Programmable Logic Arrays, Digital Signal Processors, Field Programmable Gate Arrays {FPGAs), etc.) shall be specified, designed, developed, reviewed, configuration controlled, and tested in the same rigorous manner as the flight software.

5.2 Flight Software Modularity

The HRV flight software shall be written in modular or object-oriented form so that functional units of code can be modified on-orbit with minimal impact to operations.

5.2.1 Software Module Upload

The flight software shall be capable of being uploaded in modules, units, segments, or objects that shall be usable immediately after completion of an upload of the modified modules, units, segments, or objects. Activation of the modified modules, units, segments, or objects shall not require completion of an upload of the entire flight software image.

5.3 Flexibility and Ease of Software Modification

The HRV flight software design shall be flexible and table-driven for ease of operation and modification. It shall be capable of scheduling and prioritization of critical tasks to ensure their timely completion. Limits and triggers for anomaly responses shall be readily accessible and changeable by ground command.

5.3.1 Tables

All HRV flight software data that are anticipated to be modified or examined by ground operators shall be organized into tables. The flight software shall have knowledge of the location of each table such that ground operators need only reference a table number (for the entire table), or a table number and position within the table (for a partial table). The flight software shall internally maintain table physical memory locations such that the ground can load and dump tables without the knowledge of where the data resides in physical memory, and no ground software or database change shall be required when the data is relocated due to a recompilation of the flight software. The FSW shall also accommodate a 30% table growth over the lifetime of the mission.

5.3.2 Command Definition Independent from Processor Physical Memory Locations

The definition of HRV commands within the ground database shall not be dependent on physical memory addresses within the flight software. All commands processed by the flight software (with the exception of Section 5.11) shall be interpreted by the flight software without the use of any uploaded physical address. Existing command definitions in the database shall be unaffected when the flight software is recompiled.

5.4 Version Identifiers in Embedded Code

All software and firmware shall be implemented with internal identifiers embedded in the executable program or image indicating the version of the currently installed software/firmware to ground operators.

5.5 Flight Processor Resource Sizing

All multifunction flight software systems shall meet the resource utilization requirements identified in section 5.5.1.

5.5.1 Multifunction Flight Processor Resource Sizing

During development, flight processors providing computing resources for HRV subsystems shall be sized for worst case utilization not to exceed the capacity shown below (measured as a percentage of total available resource capacity):

Multifunction Flight Processor Resource Utilization Limits

Resource/Phase	S/W PDR	S/W CDR	S/W AR
Memory	40%	50%	60%
CPU	30%	40%	50%
I/O Bandwidth	30%	40%	50%
Bus Utilization	30%	40%	50%

5.5.1.1 Resource Utilization Monitors

The flight software for multifunction software systems shall provide the capability to monitor the resource utilization by software subsystems or critical functions. The resource utilization monitors shall be available for downlink in telemetry.

5.6 Responsiveness to Ground Originated Changes

The HRV flight software design shall accommodate processing of ground commands, on-orbit revisions to software and telemetry formats, computer self checks, redundancy management, and mode changes.

5.7 Software Event Logging in Telemetry

The HRV flight software shall include time-tagged event logging in telemetry. The event messages shall capture anomalous events, redundancy management switching of components, and important system performance events.

5.7.1 Event Message Format

All flight software components shall utilize a common format for event messages.

5.7.2 Event Message Identification
Each event message shall have the means to identify the source processor, source software task or function, severity level, type of event (such as hardware, software, informational), a message number, and an optional text string that relates the cause of the event.

5.7.3 Event Message Queue
The flight software shall buffer a minimum of 300 event messages while the event messages are queued for telemetering to the ground.

5.8 Initialization
The flight software shall provide for separate Cold Restart and Warm Restart initialization processing. The contractor shall derive the Cold Restart and Warm Restart initialization functional, performance, and design requirements to satisfy all HRV requirements.

5.8.1 Cold Restart Initialization
The flight software shall execute the Cold Restart initialization processing when starting execution from a hardware reset. The Cold Restart initialization shall execute from non-volatile memory, shall reset the command counter, and shall restore default telemetry contents.

5.8.1.1 The flight software shall provide a command that will affect a cold restart of the flight software.

5.8.2 Warm Restart Initialization
The flight software shall execute the Warm Restart initialization processing when restarting the flight software from software command. The Warm Restart Initialization shall preserve command processing statistics, and shall preserve memory tables and command sequences that were previously uploaded.

5.8.2.1 The flight software shall provide a command that will affect a warm restart of the flight software.

5.8.2.2 The flight software shall increment a Warm Restart counter by one (1) each time the Warm Restart software functionality is executed.

5.8.2.3 The flight software shall report the Warm Restart counter in routine telemetry.

5.8.2.4 The flight software shall provide a command to reset the Warm Restart counter to zero.

5.8.3 Avoid Warm Restart Loops
When the Warm Restart count equals or exceeds a commandable parameter, the flight software shall affect a Cold Restart in lieu of the Warm Restart.

5.8.4 Failsafe Recovery Mode
The flight software shall provide a failsafe recovery mode that depends on a minimal hardware configuration with all interrupts disabled and is capable of accepting and processing a minimal

command subset that is sufficient to load memory and begin execution at a specified memory address.

5.9 On Board Autonomy
The HRV shall have the ability to autonomously perform reconfiguration of redundant components as required to enter into a safe mode.

5.9.1 Autonomous Reconfiguration Limit
Autonomous reconfigurations shall not be required for normal operations of the HRV or its components.

5.9.2 Ground Override of Autonomous Anomaly Responses
All flight software autonomous functions, automatic safing, or switchover capabilities shall be capable of being separately disabled, enabled, executed, or over-ridden, or aborted by ground command.

5.9.3 Reconfiguration Notification
All autonomous equipment reconfigurations initiated by the flight software shall be reported in normal telemetry, and shall generate a critical event message.

5.9.4 Component Status Determination
The flight software shall interrogate and determine the status of HRV components.

5.9.5 Retain Component Status
The flight software shall retain knowledge of the status of redundant components following processor restart, processor failover, RAM memory loss, or bus undervoltage so that the HRV avoids switching to previously failed components.

5.10 Failure Detection and Correction (FDC)
The flight software shall monitor component, subsystem, and housekeeping data, and shall have the ability to safely configure the HRV in the event of an anomaly.

5.10.1 Flight Software Monitors
The flight software shall provide a table driven means for verifying proper execution of critical software tasks or functions, and shall perform a corrective action via stored command sequence(s) in the event that one or more of the critical tasks fails to meet performance requirements.

5.10.2 Health and Safety Monitor Table
The flight software shall provide a table driven mechanism for defining anomalous conditions and the corrective action(s) to be performed in response for each condition.

5.10.2.1 Health and Safety Monitor Table Entries
The anomalous conditions defined in the Health and Safety Monitor table shall include software generated event messages, flight microprocessor component status data, and all subsystem, software, and housekeeping data.

5.10.2.2 Ground Control of Health and Safety Monitor Table
The Health and Safety Monitor table as a whole, and single entries within the table, shall be enabled, disabled, loaded and dumped by ground command.

5.10.3 Watchdog Timer
The flight software shall update the watchdog timer at a TBS rate when all critical software functions are executing nominally.

5.10.4 Memory Tests
The flight software shall provide a mechanism to verify the contents of all memory areas.

5.11 Memory Location Dump Capability
The flight software, and associated on-board computer hardware, shall provide the capability to dump any location of on-board memory to the ground upon command by referencing its physical memory address.

5.11.1 Memory Dumps During Normal Operations
The flight software memory dump capability shall not disturb normal operations or HRV data processing.

5.12 Memory Dwell
The flight software shall provide a mechanism to telemeter the contents of selected addresses in memory to support debugging efforts and provide additional telemetry points which may have been unanticipated at development time.

5.12.1 Dwell Tables
The memory dwell function shall have the ability to sample selected memory addresses at rates exceeding the rate at which the dwell data is reported in the telemetry stream.

5.12.2 Multiple Dwell Tables & Rates
The memory dwell function shall read memory values whose addresses are stored in **TBS** dwell tables of **TBS** addresses each. The data specified in each table shall be sampled at **TBS**-Hz.

5.12.3 Dwell Table Control
Each of the dwell tables, and each entry within each table shall be capable of being enabled, disabled, loaded, or dumped via ground command.

5.13 Stored Commands
The HRV flight software shall provide two types of stored commanding: stored absolute-time command sequences, and stored relative-time command sequences.

5.13.1 Absolute-Time and Relative-Time Stored Commands
All requirements in section 5.13.1 apply to both types of stored command sequences.

5.13.1.1 Stored Sequence Modifications
The absolute-time and relative-time stored command sequences shall be modifiable by ground command including the addition and deletion of separate command sequences.

5.13.1.2 Command Sequence Table Dumps
The absolute-time and relative-time stored command sequence capability shall be designed so that each stored command sequence table can be dumped to the ground by a single, simple command and not by an elaborate memory dump procedure.

5.13.1.3 Sequence Identification
Each absolute-time and relative-time stored command sequence shall have a unique identifying name or number.

5.13.1.4 Sequence Thread Identification
The HRV shall use the unique command sequence identifiers to report the status of each actively executing command sequence in telemetry.

5.13.1.5 Stored Sequence Control
Individual absolute-time and relative-time command sequences shall be enabled, disabled, paused, or cancelled by ground command.

5.13.1.6 Stored Command Sequence Timing Accuracy
The resolution of the least significant bit of the specified time shall be **TBD**. The flight software shall send stored commands within **TBD** seconds of the requested time.

5.13.2 Absolute-time Stored Command Sequences
The HRV shall provide the capability to store multiple sequences of absolute-time time-tagged commands, and to execute those commands at the absolute time identified in the time-tag associated with each command in the sequence.

5.13.2.1 Concurrent Absolute-time Command Sequence Execution
The HRV shall have the ability to execute **TBS** (multiple) absolute-time stored command sequences concurrently.

5.13.2.2 Relative-time Sequence Activation
Absolute-time stored command sequences shall be capable of invoking relative-time stored command sequences.

5.13.3 Relative-time Stored Command Sequences
The HRV shall provide the capability to store multiple sequences of relative-time time-tagged commands, and to execute those commands at the time identified in the time-tag associated with each command in the sequence.

5.13.3.1 Concurrent Relative-time Command Sequence Execution
The HRV shall have the ability to execute **TBS** (multiple) relative-time stored command sequences concurrently.

5.13.3.2 Relative-time Command Time-Tags
Each command of a relative-time stored command sequence shall have a time-tag that specifies a variable delta time interval relative to the time that the previous command in the sequence was executed. A relative-time of zero for the first command of a relative-time command sequence shall indicate that it is to be executed immediately upon sequence activation.

5.14 Software Development & Validation Facility (SDVF)
The fidelity of the HRV SDVF and its two copies, the FSW Development and Validation Facility (FDVF) and HRV Training Simulator, shall be such that all HRV flight software requirements may be validated. Hardware and simulation software shall provide all inputs and responses for validation of interface requirements and timing. All HRV subsystem functionality shall be modeled even if not actively controlled by flight software because of the requirements of 5.14.3 and 5.14.4 below. A Logic Analyzer and/or bus monitor shall be included for detailed FSW probing.

5.14.1 SDVF and FDVF Flight Segment Simulation Performance
This testbed shall provide accurate simulation of software task execution, input/output functions, timing, dumps, and other engineering data. The testbed shall provide an accurate space environment and generate high fidelity engineering data for validation of the technical and operational requirements that are implemented by flight software.

5.14.2 SDVF and FDVF Ground Segment Performance
Automated test procedures/scripts shall interact with the Flight Segment simulator to create a closed loop dynamic simulation system. Spacecraft or instrument anomalies shall be injected, and the performance of the flight software observed. The facility shall be capable of post-processing the engineering and science data, including multiple point plotting of flight processor memory, telemetry, and software simulation data.

5.14.3 Spacecraft Training Simulator
The Training Simulator shall be a copy of the SDVF, delivered to the government for training of the Flight Operations Team personnel and validation of the HRV flight operations procedures. The fidelity of the software and hardware models shall be sufficiently high, and the performance shall match the performance of the HRV software and hardware, such that both nominal and anomalous HRV conditions may be created and observed. The Flight Operations Team

commanding via the ground segment shall produce a flight-like response from the Training Simulator.

5.14.4 Similarities of Three Simulator Facilities

The Software Development & Validation Facility, the FDVF, and the Training Simulator shall be based on a single set of operational and performance requirements that encompass the multiple uses of the simulators. The hardware elements shall be interchangeable to facilitate rapid response to equipment failure via component swapping.

6.0 De-orbit Module Requirements

6.1 GENERAL

This section establishes the top-level requirements for the configuration, performance, and verification of the Hubble Space Telescope (HST) Robotic Vehicle (HRV) De-orbit Module (DM) element. The DM is a key element of the HRV. The previous sections provide the requirements for the HRV.

The HRV will be used to provide HST with a controlled re-entry capability and to implement a robotic servicing mission.

The DM will perform the traditional free-flying "spacecraft bus" functions of the HRV with the following additions and exceptions.

1. The DM controls the HRV orbit and attitude from orbit insertion (by the ELV) through Ejection Module (EM) jettison at the end of servicing operations. However, the DM uses GN&C actuator subsystems (propulsion and reaction) that reside in the EM for this purpose. After the completion of HST servicing, these actuators will be jettisoned along with the EM.
2. The DM is intended to be permanently attached to the HST after docking and will remain attached through end-of-mission (EOM) for the HST. At that time, the DM will provide the HST with a controlled re-entry capability. The DM houses all GN&C subsystems required for this re-entry function.
3. The EM will be built in-house at GSFC, and HRV integration will be done at GSFC. The EM will contain subsystems and actuators that are used for (1). The EM contains replacement hardware for HST as well as the robotics that effect servicing. In a general sense, it is a disposable stage of a two-stage system.
4. The DM mechanical structure accommodates components for HST battery and gyroscope augmentation.
5. The DM controls all aspects of automated rendezvous and capture (AR&C). It may use the GA that is mechanically and electrically attached to the EM for grappling during docking. This arm is controlled by the DM through EM interfaces.
6. The DM controls all aspects of robotic servicing for HST.
7. The DM provides the primary EM separation and jettison capability. A redundant capability resides in the EM.
8. The DM must be able to provide a controlled re-entry capability for HST independent of the state of the HST both at the time of capture as well as at end-of-mission.

Figure 6-1. DM Conceptual Block Diagram. (TBD)

6.1.2 DOCUMENT ORGANIZATION

This document has been divided into the major sections of Introduction, Applicable Documents, Requirements, and Verification. Within the Requirements section, the requirements are specified by mission operational phase since the DM performs different functions for these phases.

6.1.3 CONTENT STATUS

The information contained in this document represents the current definition of the performance requirements for the DM in all areas except where noted by a To Be Determined (TBD) or To Be Resolved (TBR). TBD indicates that the information required is not available, even in preliminary form. TBR indicates that the information is the best available at the time but final details remain to be resolved.

6.1.4 DOCUMENT CHANGE PROCEDURE

Once this document is baselined, any changes, including the removal of a TBD or TBR must be done formally. This requires that a Configuration Change Request be processed through the HST Configuration Control Board.

6.2 APPLICABLE DOCUMENTS

Applicable documents are provided in Section 2.0 of this document.

6.3 REQUIREMENTS

The requirements below are organized by mission phase, starting with a brief description of the phase. The first section for general requirements is applicable to all phases.

6.3.1 GENERAL REQUIREMENTS

6.3.1.1 Mission Phases

The DM will perform different functions during the various mission phases for the Hubble Robotic Servicing and De-orbit Mission (HRSDM). These phases are defined to be 1) Launch through Orbit Insertion, 2) Orbit Insertion through Capture (and docking), 3) HST Servicing, 4) EM Jettison, 5) HST Science Operations, and 6) HST Re-entry. These are described in more detail in **Sections 6.3.2 through 6.3.7** below.

6.3.1.2 Mission Requirements

The design of the DM shall be consistent with the Level I Requirements (**STR-78 Addendum**) for the HRSDM, and the HRV Mission Level II/III Requirements (**STR-TBR**).

6.3.1.3 Highest Mission Priority

The highest priority function for the DM shall be providing HST with a safe end-of-mission re-entry capability. This function shall be accomplished independent of the state of HST.

6.3.1.4 DM Element Function

In general, the DM is responsible for HST re-entry, HST battery and some portions of gyroscope augmentation, and GN&C, C&DH, communication, and power for the HRV over all phases of its mission. Special considerations for DM design are required to optimize the various functions that the HRV needs to provide.

6.3.1.4.1 Top-Level Functions

The DM shall be capable of initial attitude determination after launch vehicle separation. The rate null shall be accomplished within 100 min (TBR). The DM shall provide all necessary vehicle control modes to pursue, capture, dock, service, and de-orbit the HST. These include control modes which enable solar power generation, thermal stability, orbit maneuvers, momentum management, HST acquisition and tracking, HST capture, HST rate null, and safe hold. During the science operations phase, the DM control system will be inactive.

The DM shall provide all absolute and relative navigation capability to support the pursuit, capture, docking of HST. The DM shall support on-board absolute and relative navigation. The

DM navigation system shall also support servicing and de-orbit by providing absolute navigation. The DM navigation system will be inactive during the science operations phase.

If HST onboard attitude determination is functional, it will be made available to the DM relative navigation system through the ground system.

The DM control system shall be capable of executing ground up-linked maneuver commands during the pursuit and proximity operations phase. The DM shall be capable of on-board maneuver planning and execution during the proximity operations and capture. The transition from ground-based maneuver planning to on-board maneuver planning will occur during proximity operations. All de-orbit maneuvers will be planned from the ground.

6.3.1.4.1.1 Pursuit, Proximity Operations, Capture, and Docking

The DM element shall effect pursuit, proximity operations, capture, and docking of the HRV with the HST.

6.3.1.4.1.2 Control of Servicing Activities

Commanding of the servicing activities shall be controlled through the DM.

6.3.1.4.1.3 HST Augmentation

The DM shall provide battery augmentation and some portions of gyroscope augmentation for HST per Section 3.2.4.1.

6.3.1.4.1.4 HST Re-entry

The DM shall provide HST with a controlled re-entry capability at end-of-mission.

6.3.1.4.2 DM/EM Functional Partitioning

6.3.1.4.2.1 Orbit and Attitude Control Actuators

6.3.1.4.2.1.1 Actuator Location Before EM Jettison

The actuators that effect control of the HRV from launch through EM jettison shall reside in the EM. The DM shall provide the necessary interfaces (and specifications) for the required control elements.

Rationale: Pre-docking orbit and attitude control resources are not needed after servicing, and will be ejected with the EM to minimize HST attached mass. Full tanks on the DM (to support re-entry) minimize risk of "sloshing" to HST pointing.

6.3.1.4.2.1.2 Actuator Location After EM Jettison

The actuators that effect control of the HST plus DM after EM jettison (for re-entry operations) shall reside in the DM.

The actuators that effect control of the EM after EM jettison (for re-entry operations) shall reside in the EM.

6.3.1.5 Major Mechanical Interfaces

6.3.1.5.1 HST

The DM shall attach to the HST. The direction of the DM that is closest to the HST after attachment shall be referred to as the "fore" end.

6.3.1.5.2 Ejection Module

The DM shall attach to the Ejection Module (EM). The EM shall be at the opposite ("aft") end from HST to accommodate jettison.
Rationale: The EM carries up the new ORUs and SIs for HST servicing and augmentation, stores the items removed from the HST, and carries items necessary for orbit and attitude control before docking with HST. The EM is intended to be jettisoned after servicing operations are completed in order to minimize attached mass to the HST. The most efficient arrangement thus has the EM at the opposite end from the HST.

6.3.1.6 Coordinate System

The coordinate system axes used for the DM shall be parallel to the HST coordinate system defined in **Section 3.1.2**.
Rationale: This terminology minimizes confusion during and after docking. Note that there is an offset in V1/D1 between the origins of the HST and DM coordinates.

6.3.1.7 Design Lifetime

6.3.1.7.1 Before Launch

The DM shall be designed for a two year lifetime after delivery before launch without any impact to performance per Section 4.1.12.1.

6.3.1.7.2 Orbit Insertion Through Docking

The DM shall provide pursuit, capture and docking capability for the period as defined in Section 3.2.1.6. At any time during this period, the DM shall be able to continue with the later mission phases with no impact to performance.

6.3.1.7.3 HST Science Operations

The DM shall provide science mission support as defined in Section 3.2.4.4.

6.3.1.7.4 Re-entry Capability

The DM shall be able to execute a controlled re-entry of the combined HST/DM spacecraft as defined in Section 3.2.2.2

6.3.1.8 Communication

The DM shall receive commands and send telemetry during all phase of the mission.

6.3.1.9 Power

The DM shall provide its own power for all phases of its mission.

Rationale: The DM needs to be independent of any other entity in providing the re-entry capability. Additional power may be required by both the HST and by the EM during servicing, as described in **Section 6.3.4.3.1**.

6.3.1.9.1 Ground Return Isolation

The DM shall provide ground return isolation as specified in Section 4.1.2.4.

6.3.1.10 DM Interface to the HST486

The DM shall provide an ERC interface for harnessing to connect the DM C&DH to the HST486 using a MIL-STD-1553B bus.

6.3.1.11 Reliability

The DM shall have reliability and fault tolerance as defined in Section 4.1.11.

6.3.1.11.1 Control Computer Configuration

The DM C&DH shall have the capability to run in shadow mode with hot backup.

6.3.1.11.2 Safe Hold Computer

The DM C&DH shall provide an independent safe hold computer in the event of main and backup computer failure.

6.3.1.11.3 HST Fault Isolation

No fault in the HST system shall be allowed to propagate into the DM. The DM shall provide any and all safety circuitry required for HST fault isolation.

6.3.1.12 Ground Monitoring

6.3.1.12.1 Video Transmissions

The DM shall provide real-time video per Section 4.1.5.

6.3.1.12.2 Communication Link Properties

6.3.1.12.2.1 High Gain Antennae

The DM shall make use of High Gain Antennae capability on the EM.

6.3.1.13 Ground System and Communication

6.3.1.13.1 Compatibility

The DM ground system shall provide a set of application program interfaces via an IP interface that allows an external system to control DM ground system functions, receive telemetry from the HRV, and send commands to the HRV.

6.3.1.13.2 DM Communication Interfaces

6.3.1.13.2.1 Communication with the EM

Prior to EM ejection, the DM shall provide a communication interface for the EM that allows the EM to communicate with the ground system.

6.3.1.13.2.2 Low Gain Communication

The DM shall provide a low gain capability for direct communication with TDRSS, GSTDN or other ground stations.

6.3.1.13.2.3 Communication with HST

The DM shall provide MIL-STD-1553B interfaces for communicating with HST. See **Section 3.1** for GFE and HST486 interfaces.

6.3.1.13.3 DM Support for HST Commanding

The DM shall provide command-relaying capability for HST.
Rationale: Accommodate potential line-of-sight blockage of the HST LGA during operations.

6.3.1.13.4 Security

The DM command link shall utilize authentication and/or encryption for commands that could jeopardize the mission.

6.3.1.13.5 Ground Abort

The DM shall provide ground abort capability per Section 5.9.2.

6.3.1.14 Contamination and Cleanliness Levels

The DM shall comply with all contamination and cleanliness requirements defined in Section 3.3.3.3.

6.3.1.15 Natural Environment

The HRV shall meet natural environment requirements as defined in Section 4.1.8.

6.3.1.15.1 Radiation Tolerance

DM radiation tolerance shall be consistent with the orbit of the HST and the required lifetimes and functional reliability for the DM.

6.3.1.15.1.1 Component Selection

All electronic components shall be selected and/or shielded to minimize the potential impact of ionizing radiation, including Single Event Upsets (SEU). Components shall be capable of operating through mission life within specification after exposure to levels specified in **Section 3.3.3.4** over 7 years. This requirement may be fulfilled through device tolerances and/or additional shielding.

6.3.1.15.1.2 Control Circuitry SEU

Control circuitry shall be designed for less than one SEU in the entire system in 1 year for the HST orbit. For any device that is not immune to latch up or other potentially destructive conditions, protective circuitry shall be added to eliminate the possibility of damage and verified by test or analysis.

6.3.1.15.2 Atomic Oxygen

The design of external surfaces of the DM shall take into consideration the atomic oxygen environment of the HST orbit. The DM shall not lose functionality due to AO exposure at HST orbital altitudes, reference TMX 73331, over the de-orbit lifetime as defined in **Section 3.2.2.2.**

6.3.1.15.3 Meteoroid

The DM shall provide meteoroid protection as defined in Section 3.3.3.5.

6.3.1.16 Materials

6.3.1.16.1 Materials and Processes

Materials and processes shall be selected in accordance with **SMR-5000.** Additional design information is provided in Section 4.1.7.1.

6.3.1.16.2 Corrosion of Metal Parts

Metal parts shall be protected from corrosion by stress-reliev-ing, plating, anodizing, chemical coatings, organic finishes, or combinations thereof. Such protection shall be compatible with the contamination constraints and operating/space environmental requirements. Applications involving dissimilar metals shall be evaluated to ensure that galvanic corrosion is minimized.

6.3.1.16.3 Material Outgassing

The outgassing of organic materials used in the HRV shall meet the requirements of **STR-29**. Additional requirements that pertain to the HST AB are defined in Section 3.3.3.3.2.

6.3.1.16.4 Castings

Castings shall not be used in any part of the DM without the prior consent of the GSFC materials assurance engineer.

6.3.2 LAUNCH THROUGH ORBIT INSERTION

6.3.2.1 General Description

During this phase, all components of the HRV are a passive payload for the launch vehicle. The interface to the launch vehicle is through the Payload Attach Fitting (PAF).

6.3.2.2 Attachment to Launch Vehicle

The DM shall attach to the launch vehicle using a PAF that is on the front (+V1) end of the DM.

6.3.2.3 EM Accommodations

6.3.2.3.1 EM Mechanical Support

The DM shall provide mechanical support for the EM during launch and ascent. The EM is located at the –H1 end of the DM. The EM mass shall be assumed to be <= 17,000 lbs, the EM center of mass shall be assumed to be 240 inches in HRV coordinate system H1, 0 (**TBD**) in H2, and 0 (**TBD**) in H3, and the first structural mode shall be assumed to be > 12 Hz (**TBR**).

6.3.2.3.2 Purge Interfaces

The DM shall provide a connection between the ELV T-0 purge interface and the EM interface.

6.3.2.3.3 Power Interface

The DM shall provide an electrical power interface to the ELV T-0 power interface for pad power load support and battery charging.

6.3.2.3.4 Pad Command and Telemetry Interface

The DM shall provide the capability to receive commands and send telemetry while on the launch pad.

6.3.3 ORBIT INSERTION THROUGH DOCKING WITH HST

6.3.3.1 General Description

After orbit insertion by the ELV, the HRV will be released by the ELV, and will then become a free-flying spacecraft.

6.3.3.2 Autonomy

The DM shall effect capture, and docking with HST with minimal ground interaction after in-orbit checkout. Orbit maneuvers in the pursuit and de-orbit phases will be planned from the ground.
Rationale: Detailed ground control of time-critical functions is not practical. Minimal can be interpreted to mean activation commands, uplinking of guidance and navigation information, updates on HST coordinates, and similar information.

6.3.3.3 Guidance, Navigation, and Control

6.3.3.3.1 DM Responsibilities

The DM shall perform all guidance, navigation, and control functions for the combined HRV during this phase of the mission.
The DM shall provide all necessary vehicle control modes for the HRV to rendezvous, capture, dock, and service the HST. These include control modes which enable solar power generation, thermal stability, orbit maneuvers, momentum management, HST acquisition and tracking, HST capture, HST rate null, and safe hold.

6.3.3.3.2 DM Sensors

The DM shall provide or specify all the sensor systems required to perform its GN&C functions, consistent with **Section 6.3.1.4.2**.

6.3.3.3.2.1 DM Relative Navigation Sensors

The DM shall provide all necessary measurement data relative to HST during pursuit, capture, and docking using a minimum of two different sensor types. The relative navigation sensors and the GPS receiver shall make their raw data as well as any processed outputs available to the ground.
The DM shall provide functionally redundant, independent relative navigation sensors that provide overlapping range and orientation data coverage from 100 m to 2 m and a minimum of one sensor down to 0.1 m (relative range to HST). The DM shall provide range data at ranges less than or equal to 3 km.

6.3.3.4 Plume Impingement

The DM shall control HRV thruster plume impingement on the HST per Sections 3.3.2.2.1 and 3.3.3.3.5.

6.3.3.5 Pursuit

6.3.3.5.1 Altitude

The DM shall be capable of rendezvous with an un-powered HST at a maximum altitude and orbital inclination as specified in Section 3.2.1.

6.3.3.5.2 Benign Approach

6.3.3.5.2.1 Stray Light

The DM shall not cause HST response or damage due to illumination required during this phase.

6.3.3.5.2.2 Physical Contact

The DM shall not contact any part of the HST during this phase. Particular care shall be taken while in the proximity of the solar arrays and high gain antennae (**reference Section 3.3.1.3.1**).

6.3.3.6 Capture and Docking

6.3.3.6.1 HST State

Capture and docking shall be accomplished without regard to the state of the HST. The HST in an un-powered state may have a worst-case drift body rate as specified in Section 3.2.1.1.

6.3.3.6.2 Capture and Docking Attempts

The DM shall be capable of capturing and docking as specified in Section 3.2.1.2.

6.3.3.6.3 Capture Method

The DM shall support at least two independent means of HST capture.

6.3.3.6.4 Capture Arm Interface

The DM shall utilize the grapple arm located in the EM, reference Section 3.3.1.2.4) for the primary means of HST capture. The necessary command and control functions for the arm shall reside in the DM.

6.3.3.6.4.1 Primary Capture Mode

The primary capture mode shall use one of the two grapple fixtures located on the -V3 side HST (**Section 3.3.1.2.1**). This requirement shall be satisfied by appropriate use of the grapple arm that is located within the EM.

6.3.3.6.4.1.1 Grapple Fixture Limit Loads

The allowable forces at the grapple fixtures shall be as specified in **Section 3.3.2.2.2**.

6.3.3.6.4.2 Backup Capture Modes

The backup capture mode shall be as specified in Sections 3.3.1.2.2 and 3.3.1.2.3.

6.3.3.6.4.2.1 Berthing Pin Limit Loads

The allowable forces at the berthing pins shall be as specified in Section 3.3.2.2.3.

6.3.3.6.4.2.2 Trunnion/Keel Limit Loads

The allowable forces at the trunnions/keel shall be as specified in Section 3.3.2.2.3.1.

6.3.3.6.5 Docking Method

The DM shall provide three docking latches to dock the HRV to the HST using all three of the berthing pins located on the Aft Bulkhead (**Section 3.3.1.2.2**).

6.3.3.6.5.1 Docking Loads During Operations

During capture and docking operations, the loads into each HST berthing pin shall not exceed those defined in Table 3-18 “AB Berthing Pin Capability".

6.3.3.6.5.2 Docking Alignment

The DM shall ensure that the DM and HST coordinate axes are aligned to an accuracy as specific in Section 3.3.1.12.

6.3.3.6.5.3 Docking Stability

The DM docking latches shall apply clamping force four times larger than the force acting on the interface.

6.3.3.6.6 Physical Contact

The DM shall not make physical contact with the HST during capture and docking except for locations specifically targeted during these operations (e.g., the grapple fixture and berthing pins).

6.3.3.7 Post-Docking Configuration

6.3.3.7.1 Clearances

6.3.3.7.1.1 General Clearances to HST

The docked DM shall maintain a clearance in accordance with Section 3.3.1.3.2.

6.3.3.7.1.2 Clearances to Solar Arrays and HGAs

The DM design shall keep the DM out of the sweep range of the two HST Solar Arrays and HGAs as identified in Section 3.3.1.3.1.

6.3.3.7.1.3 Clearances to P105 and P106

The docked DM shall provide access to the HST P105 and P106 connectors for contingency umbilical mate by robotic means as specified in Section 3.3.1.3.3.

6.3.3.7.1.4 Field of View for Coarse Sun Sensors

The DM design shall maintain the full hemispherical field of view for CSSs as specified in Section 3.3.1.3.5.

6.3.3.7.2 Stray Light

The DM design shall minimize glints into the HST aft -V3 Coarse Sun Sensors (CSS-4, CSS-5).

6.3.3.7.2.1 DM Surface Properties

The DM front-end shall have a non-specular thermal coating that minimizes solar entrapment with the aft bulkhead. All DM external surfaces shall minimize straylight into the CSS.

6.3.3.7.3 Grounding Requirements

The DM shall be grounded to the HST by less than or equal to 10 Milliohms (TBR).

6.3.4 HST SERVICING

6.3.4.1 General Description

During this phase, the HST and HRV are a single attached object and the grapple arm on the EM is used to service the HST.

6.3.4.2 Servicing Method

The DM shall support robotic servicing by the EM (using flight actuators and monitors and ground control). This support shall accommodate tele-robotic, autonomous, and combined operations.
Rationale: Operations are too critical and complex for autonomous servicing.

6.3.4.2.1 Command and Data Communication

The DM shall provide EM subsystems with command and data communication capability so that it can perform the necessary ERC functions during this phase.

6.3.4.3 DM Servicing Accommodations

The following paragraphs describe the DM requirements for supporting HST life-extension.

6.3.4.3.1 Battery Augmentation

The HST battery augmentation is a key life-extension task for the servicing mission. It augments the HST batteries with a set that is located within the DM as specified in Section 3.3.4.2.

6.3.4.3.1.1 Input Power Characteristics

HST power to the augmentation batteries will be provided from the SA3 P6A/P8A connectors as defined in Section 3.3.4.1.

The DM shall provide SA3 reverse current isolation and switching at the string level.

6.3.4.3.1.1.1 Primary Source

The DM shall provide an ERC interface designed to provide input power (via GOE ERC-installed harnessing from the HST SA3 harness connectors) to the augmentation batteries located in the DM.

6.3.4.3.1.1.2 Backup Source

The DM EPS shall provide power to augment the HST survival eclipse load (see **Section 6.3.4.3.1.3.3**) in the event the connection of the SA3 power tap is unsuccessful.

6.3.4.3.1.2 Output Power

The HST output power shall meet the requirements as specified in Section 3.2.4.1.

6.3.4.3.1.2.1 Connection

The DM shall provide a mechanized means of connecting augmentation power to HST through the HST J101 interface (primary) using a GFE connector. The DM shall also provide an ERC-compatible interface capable of providing augmentation power to HST through the HST P105 and HST P106 deployment interfaces (backup).

The DM shall also provide an ERC interface capable of providing augmentation power to HST NCS radiator diode box J1 connector.

6.3.4.3.1.2.2 HST Continuous Power Augmentation

The DM shall provide power augmentation as defined in **Section 3.2.4.1**.

6.3.4.3.1.2.3 EM Power Augmentation

The DM and EM SA shall provide a minimum load capability as specified in Section 4.1.2.2.1.

6.3.4.3.1.2.4 WFC3 Changeout

The HRV shall provide through DM control, sun protection during the WFC3 changeout operations.

6.3.4.3.1.2.5 COS Changeout

The HRV shall provide through DM control, sun protection during the COS changeout operations.

6.3.4.3.1.3 Battery Augmentation Compatibility

The DM battery augmentation shall be compatible with the existing HST power system (see **Section 3.3.4.11**). The HST and the DM augmentation systems shall operate in parallel.

6.3.4.3.2 RSU Interfacing Accommodation

The Rate Sensor Unit (RSU) augmentation is a second key life-extension task for the servicing mission. It augments the HST on-board gyroscopes with a completely new set that is mounted onto the WFC3 instrument enclosure. The ECUs that control these new RSUs are located within the DM. The Gyroscope Input/Output Electronics (GIOE) per Figure 3-1 (ECU-to-1553 I/O Unit) are also located within the DM. Each ECU is packaged with a GIOE to form a GFE Gyroscope Interface Unit (GIU). The GIU interfaces are as specified in Section 3.3.1.6.

6.3.4.3.2.1 Interface to RSUs

The DM shall provide electrical interfaces for GOE harnessing to connect the GIU's to the RSU's located within the WFC3 instrument that will be installed during the HST Servicing phase. There will be one connector per RSU.

Rationale: Required control functions for the RSU's.

6.3.4.3.2.2 Interface to HST486

The DM shall support ERC-installable GOE harnessing to connect the GIU's to the HST486 1553 interface during the HST Servicing phase.

6.3.4.3.2.3 GIU Characteristics

Weight: 25 lbs; Envelope: 14.0 x 9.0 x 19.0 inches (H x W x L); Top Level drawing number 4176429; Static Load Limit: 22.5 g; Random Vibration Level: 14.8 g RMS; Operating Temperature Range: -24 to 60C; Non-operating Temperature Range: -45 to 60C; Thermal

Properties (α/ε) 0.96/0.87; Thermal Capacity: 3.46 BTU/°F; Contamination: 500B surface and 400 Hz/hr/cm^2 molecular; Power: 70 Watts; Voltage: 24 to 32 volts.

(This paragraph is placed here for information only. These are the specifications for a single RSU. The GIU is not expected to be substantially different. This paragraph will be replaced by a TBD reference to an appropriate specification document for the GIU.)

6.3.4.4 Servicing Activities

This section describes the DM during planned servicing activities. The DM shall perform all control and communication functions for the combined HRV during this phase of the mission, including robotic control. The replacement hardware stored in the EM and the grapple arm on the EM are expected to play the major role.

6.3.4.4.1 Battery Augmentation Hookup

The DM shall support ERC attachment of the GOE battery augmentation electrical harnessing as specified in Sections 4.1.1.4.8, 4.1.1.11.1.1 and 4.1.1.11.1.3.

6.3.4.4.2 DM C&DH to HST486 Hookup

The DM shall support ERC attachment of the DM C&DH to HST486 MIL-STD-1553B communication link electrical harnessing as specified in Sections 4.1.1.4.8, 4.1.1.11.1.1 and 4.1.1.11.1.3.

6.3.4.4.3 HST (WF/PC II) Radial Instrument Replacement

The DM design shall not impede the ERC removal of the WF/PC II scientific instrument from HST, and its replacement with the WFC3 instrument that is carried within the EM within the load limits as specified in Section 4.1.1.4.8.

6.3.4.4.4 HST (COSTAR) Axial Instrument Replacement

The DM design shall not impede the ERC removal of the COSTAR scientific instrument from the HST, and its replacement with the COS instrument that is carried within the EM within the load limits as specified in Section 4.1.1.4.8.

6.3.5 EM Ejection

At the termination of the HST Servicing Phase, the EM will be ejected from the DM. In this manner, hardware that has been removed from the HST and subsystems that have already provided their intended function for previous mission phases can be decoupled from the HST to minimize attached mass.

6.3.5.1 Ejection Mechanism

The DM shall provide a two fault tolerant mechanical/electrical ejection system for effecting mechanical detachment of the EM from the DM.

6.3.5.1.1 Ejection Velocity

The separation velocity imparted to the EM immediately after ejection shall be no less than 0.5 meters/sec.

6.3.5.1.2 Ejection Tipoff

The separation mechanism shall impart tipoff rates to HST/DM that are less than or equal to: V1<=0.138 degrees/sec, V2<=0.103 degrees/sec, V3<=0.132 degrees/sec (**TBR**).

6.3.5.1.3 Ejection Command Protection

The DM shall provide single fault tolerance to inadvertent activation of critical commands. The DM shall provide two fault tolerance to inadvertent activation of pyrotechnic commands.

6.3.5.2 Ejection Loads

6.3.5.2.1 HST Loads

The loads imparted by the DM to the HST berthing pins during EM ejection shall not exceed those described in **Section 6.3.3.6.5.1**.

6.3.5.2.2 EM Loads

The loads imparted by the DM to the EM during EM ejection shall not exceed **TBD**.

6.3.5.2.3 Ejection Separation Burn

The DM shall not be required to execute any separation burns after EM ejection.

6.3.6 HST SCIENCE OPERATIONS

6.3.6.1 General Description

During this phase, the DM is a passive mass attached to the HST. The EM has been ejected. Normal science operations are envisioned for HST using the new hardware provided by servicing. The DM performs its HST life augmentation functions through the hardware that resides within it (batteries and ECU's), and housekeeping.

6.3.6.2 General Requirements

During this phase, the HST/DM combined spacecraft shall meet all current Level I requirements in **STR-78** except those related to Shuttle-based servicing, and Level II requirements as found in **STR-125 Sections 3.1.2.2 and 3.3 (including video data)**.

6.3.6.3 Combined Inertia

The combined HST/DM inertia shall not exceed 166000 Kg-m^2.

6.3.6.4 Mechanical Disturbances to HST

6.3.6.4.1 Stiffness

The DM shall have a minimum first rigid body mode of 20 Hz (**TBR**) when docking latches are attached to "ground". All secondary modes must be higher. The combined DM/HST first rigid lateral mode shall be as specified in Section 3.3.2.3.

6.3.6.4.2 Modal Gain

6.3.6.4.2.1 Appendages

Any DM appendage during science operations shall have maximum modal gains, K_B, of 0.04 between 0 and 1 hz, and 0.02 greater than 1 hz (**TBR**). The equation defining Kb is defined in Section 4.1.1.10.1.

6.3.6.4.2.2 Propellant "Slosh"

Propellant located in the DM during science operations shall have maximum modal gains, Kb of ≤ 0.02 from 0 to 1hz, and ≤ 0.01 greater than 1 hz (**TBR**).

6.3.6.4.3 Disturbance Torques

The DM during science operations shall limit the disturbance torques across the HST AB to less then .004 newton meters (0.035 in-lbf).

6.3.6.4.4 EOD/EON Transients

The DM during science operations shall limit any Enter Orbit Day (EOD) or Enter Orbit Night (EON) thermal change impulse transients to a maximum angular momentum change of 0.018 newton-meter-second (0.16 in-lbf-sec).

6.3.6.4.5 HST Low Gain Antenna Blockage

The combined HST/DM after servicing and EM jettison shall not reduce the HST Aft Shroud Low Gain Antenna coverage below 95% (**TBD**) and communication signal strength by 1.7 dB (**TBD**).

6.3.6.5 Verification of Re-entry Function

6.3.6.5.1 Test Mode

The DM shall provide a commandable test mode that verifies the aliveness of the re-entry system to the reliability level specified in **Section 6.3.1.11**. This test mode shall execute with no permanent effect on HST operation.

6.3.6.5.2 Test Frequency

This test mode shall be executed more than three times after launch and before re-entry.

6.3.7 HST RE-ENTRY

6.3.7.1 General Description

Safe re-entry for the HST/DM combined spacecraft is the primary requirement of the DM and the servicing mission.

6.3.7.2 General Requirement

The DM shall be capable of performing a controlled re-entry of HST/DM combined spacecraft in accordance with **NPD 8710.3**.

6.3.7.3 HST State

The DM shall ensure that re-entry success shall not depend upon the health or configuration of the HST.

6.3.7.4 Guidance, Navigation, and Control

The DM GN&C subsystem shall perform the HST/DM combined spacecraft re-entry operations.

6.3.7.5 Mechanical Loads

6.3.7.5.1 HST Acceleration

The acceleration of the coupled HST/DM system during propulsive burns shall be less than or equal to 0.1 G.

6.3.7.5.2 Interface Loads

The loads imparted by the DM to the HST berthing pins during re-entry shall not exceed those described in **Section 6.3.3.6.5.1**.

6.3.7.6 Re-entry Command Protection

The DM shall provide single fault tolerance to inadvertent activation of critical commands. The DM shall provide two fault tolerance to inadvertent activation of pyrotechnic commands.

6.3.8 SOFTWARE

Refer to **Section 5.0** for overall HRV software requirements.

6.3.9 GROUND OPERATIONS

6.3.9.1 Ground Handling

The DM shall be capable of being handled ±H3 vertical and –H1 vertical for installation into or removal from its interfaces using standard Ground Support Equipment (GSE) lifting devices. The DM shall be –H1 vertical for system level thermal-vacuum testing. All handling fixtures required to be used at KSC shall be certified per **KHB 1700.7** and supplied with the flight hardware.

6.3.9.2 Ground Handling Loads

Ground handling loads shall be less than flight loads.

6.3.9.3 Ground Handling Environment

During all ground and prelaunch operations (except transportation and storage), the DM environment will be maintained as specified in Section 3.3.3.7.

6.3.9.4 Transportation Environment

During transportation, the environment shall be controlled to the requirements as specified in Section 3.3.3.7.

6.3.9.5 Storage Environment

The DM shall be designed to be stored in a normal laboratory environment as specified in Section 3.3.3.7.

6.3.9.6 Shipping

The environment experienced during shipping shall not exceed the limits of Section 3.3.3.7.

6.3.9.7 Identification and Marking

A parts identification and marking system shall be maintained. Each piece part, including flight spares and test items, shall be identified by a serial number. Parts lists shall be maintained at all subassembly and assembly levels to provide traceability.

Other markings to facilitate integration and testing shall be incorporated on the flight hardware as required.

6.3.10 SAFETY

Refer to **Sections 3.3.8 and 4.1.10** for overall HRV safety requirements.

7. VERIFICATION

The contractor shall develop verification matrices to determine that the HRV complies with the design, construction, and performance requirements as specified in Sections 3, 4, 5 and 6 of this document. Verification shall be by test, analysis, demonstration, validation and inspection, or any combination required to ensure compliance with all applicable requirements. The product assurance requirements defined in SMR-5000 shall be satisfied.

7.1 VERIFICATION METHODS

Qualification and acceptance shall be accomplished by any one or more of the methods outlined in STR-126. Pressurized components and systems shall be subjected to tests specified in Section 7.1.1 below.

7.2 VERIFICATION COMPLIANCE

Verification compliance with the requirements of Sections 3,4,5 and 6 shall be demonstrated to provide operational certification of the HRV. The verification of requirements shall be per the verification compliance matrix given in Table 7-1 (TBD).

Table 7-1 (TBD)

Verification Compliance Matrix

Deliverable Item List and Schedule (DILS)

for the

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

HST HRV DM DILS

The Hubble Space Telescope (HST) Robotic Vehicle (HRV) De-orbit Module (DM) Contract Deliverable Item List and Schedule (DILS) provides more specific information on the deliverable items, listed in the DM Contract Statement of Work (SOW).

The table below provides a listing of all contract deliverables including the following information:

ID: This is a sequential numerical identifier for each item.

Title: This provides the Title and, if appropriate, a brief description of the deliverable item. Note: if the item contains (DRD XX-nn), this refers to a contract deliverable referenced in the DM Statement of Work (SOW) and described in the DM Data Requirements Document (DRD).

Schedule: This provides the fixed or relative date or time that the deliverable is required.

SOW Ref: This provides a specific section(s) reference in the DM Statement of Work (SOW) for which the deliverable is required.

Action Required:

A = Approval – Documents in this category require Government review and approval prior to final acceptance. The Government will adhere to a controlled schedule for review of the initial submittal and subsequent changes. Documents shall meet specific format requirements, as specified in the HST Configuration Management Procedures (reference **TBD**) and content requirements, as defined in the DM Data Requirements Document . Deviations from the controlled schedule or format will be considered on a case by case basis.

R= Review – Documents in this category do not require formal Government approval. They must be received within a specified time period and are subject to evaluation. The Government reserves the time-limited right of disapproval for each submission. No prescribed format is specified although a recommended format may be found in the DM Data Requirements Document.

I = Information – Documents in this category are informal and are for information only.

CM Control: Documents in this category will be controlled by Government Configuration Management. (This category is intended to include all documents that affect segments, elements, subsystems and interfaces that are not completely under the Contractor's control.)

Quantity: This provides the required number of hardcopies for the deliverable. All data is required to be submitted electronically (reference paragraph 3.2.1 of the DRD for the electronic format). The number in the quantity column refers to the number of hard copies required.

Deliverable Schedule:

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
PM-01	Management Plan	Due on contract award + 30 days. Update as required.	1.0 1.2	A		3
PM-02	Monthly Status Reports	Due monthly, 10 working days following the month being reported.	1.0 1.2 1.4 2.3.1.2.1	R		Deliver electronically to distribution list provided by CO + 3 hardcopies
PM-04	Weekly Activity Reports	Due weekly on last day of each work week.	1.0	I		Deliver electronically to distribution list provided by CO + 1 paper
PM-06	Monthly Contractor Financial Management Reports (533M)	Due monthly on 15th of the month following the month being reported.	1.1	R		6
PM-07	Quarterly Contractor Financial Management Reports (533Q)	Due quarterly on 15th of the month following the quarter being reported.	1.1	R		6
PM-08	Earned Value Management System Implementation Procedures	Due 90 days after contract award. Update as required.	1.1	R		6
PM-09	Monthly Earned Value Management System Cost Performance Reports	Due monthly ten days after the close of the monthly accounting period.	1.1	R		6
PM-10	Integrated Baseline Review (IBR) Package	Due on contract award + 30 days.	1.1	R		Deliver electronically. + hardcopy
PM-100	Project Schedules	Due monthly, 10 working days following the month being reported.	1.2	R		6,

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
PM-33	Configuration Management Plan	Due on contract award + 30 days. Update as needed.	1.3 1.3.1	A		5
PM-35	System Requirements Review (SRR)	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-37	Preliminary Design Review (PDR)	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-39	Critical Design Review (CDR)	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-40	Contributions to Mission Operations Review (MOR)	Draft due 20 working days prior to the review. Final due 10 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-41	Test Readiness Review (TRR)	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4 8.2	R		Draft 10 Final 100 Follow-up 10

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
PM-42	Contributions to Operations Readiness Review (ORR)	Draft due 20 working days prior to the review. Final due 10 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-43	Pre-Shipment Review (PSR)	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	1.4	R		Draft 10 Final 100 Follow-up 10
PM-47	Risk Management Plan	Due on contract award + 30 days. Update monthly.	1.7 7.1.4.1.2	A		10
SE-01	Systems Engineering Plan	Due on contract award + 30 days. Update as needed.	2.1	A		5
SE-02	Electromagnetic Compatibility (EMC) Control Plan	Preliminary version due at PDR. Final version due at CDR. Update as required.	3.5	R		5
SE-03	Fault Protection Requirements Document	Due at PDR. Update as required.	2.3.3	R		10
SE-04	Fault Protection Description Document	Due at CDR. Update as required.	2.3.3	R		10

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
SE-05	Math Models Data Package	Provide models and supporting documentation 30 days prior to major reviews (SRR, PDR, CDR) Provide status of modeling effort, and results of analysis at major reviews (PDR, CDR). Provide interim results and updates as required.	2.3.1.2.1 4.0 5.5 6.4 6.5 6.6	A		10
SE-06	Inputs to De-orbit Module to HST ICD	30 days before PDR.	2.2.5.1	A	YES	10
SE-07	De-orbit Module to Ejection Module ICD	Draft by proposal submission. Updates by PDR.	2.2.5.1 6.1 7.1.1	A	YES	10
GNC-01	GN&C Planning Document	Due on contract award + 30 days. Update as needed.	6.1	A		5
GNC-03	DM Mass Properties	Due on contract award + 30 days. Update as needed.	6.1	R		5
GNC-04	GN&C Hardware Specifications	Preliminary at SRR Update as needed. Final at CDR	6.4	A	YES	5
GNC-05	ADCS Performance Analysis	Preliminary at PDR Final at CDR	6.2	R		5
GNC-06	Trajectory Analysis and Maneuver Planning Document	Due on contract award + 60 days. Update as needed. Final at CDR	6.3	A	YES	10
GNC-07	Orbit Determination Performance Analysis	Preliminary at PDR Final at CDR	6.4	R		5

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
GNC-08	Propulsion Fluid Analysis	Preliminary at PDR Final at CDR	6.5	A		5
GNC-09	Propulsion System Tank Fracture Control Analysis	Preliminary at PDR Final at CDR	6.5	R		5
GNC-10	Contamination Control Analysis	Preliminary at PDR Final at CDR	6.5	R		5
GNC-11	Residual Fuel/Oxidizer Analysis	Preliminary at PDR Final at CDR	6.5	R		5
GNC-12	Relative Control Performance Analysis	Preliminary at PDR Final at CDR	6.6	A	YES	5
GNC-13	Relative Navigation Performance Analysis	Preliminary at PDR Final at CDR	6.6	A	YES	5
GNC-14	Coupled Motion Analysis	Preliminary at PDR Final at CDR	6.6	A	YES	5
GNC-15	Plume Impingement Analysis	Preliminary at PDR Final at CDR	6.6	A	YES	5
GNC-17	GN&C Test Plan	Preliminary at PDR Final at CDR	6.1	R		5
GNC-18	GN&C Test Procedures and Results	Preliminary at PDR Final at CDR	6.1	A		5
GNC-19	GN&C Acceptance Test Report	Preliminary at PDR Final at CDR	6.1	A		5

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
GNC-21	GN&C Requirements Specification	Due at contract award +60 days Update at SRR	6.1	A		5
SW-01	Software Management Plan	Due on contract award + 10 days Update at SWRR	7.2	A		5
SW-02	Software Delivery and Operations Transition Plan	Due on contract award + 10 days Update at SWPDR	7.2	A		5
SW-03	Software Development Activities Plan (SDAP)	Due on contract award + 60 days Update at SWRR	7.2	A		5
SW-04	Software Requirements Specification (SRS)	Preliminary at SWRR Updates at SWPDR, SWCDR, SWAR, and as-built at launch	7.1.1 7.2.1 7.2.3	A		5
SW-05	Algorithms Design Document(s) (ADD)	Preliminary at Subsystem PDR Final at Subsystem CDR	7.2.2	A		5
SW-06	Software Design Document (SDD)	Preliminary at SWPDR Final at SWCDR Updates at SWTRR As-built at launch	7.2.2	A		5
SW-07	Software Test Plan (STP)	Preliminary at SWRR, SWPDR, and SWCDR Final at SWTRR	7.2.3	A		5
SW-08	Software Test Procedures and Results (STPr)	Preliminary at SWCDR Final Procedures at SWTRR Updates at SWAR and as-built at launch	7.2.3	A		
SW-09	Software Test Reports (STR)	Final at SWAR Updates as generated	7.2.3	A		5

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
SW-10	Version Description Document (VDD)	As generated with software releases	7.2.3	A		5
SW-11	Software User and Maintenance Manual (SUMM)	Preliminary at SWCDR Final at SWAR Update to as-built at launch	7.2.2	A		5
SW-13	Software Development and Validation Facility User's Manual	Due with SDVF/FVMF/Training Simulator facility deliveries Updates at SWAR and as-built at launch	7.2.2	A		5
SW-14	Software Development Files (SDFs)	Final at software transition after launch	7.2.4	A		
SW-15	Software Review Packages	Draft due 10 working days prior to the review. Final due 2 working days prior to the review. Follow-up reports due 5 working days after conclusion of review.	7.2.2 7.3.4	A		30
SW-16	Software Measures (Metrics) Report	As generated monthly	7.3.3	A		8
SW-17	Training Materials	Final at SWAR	7.2.3	A		30
SW-18	Subsystem High-Level Software Simulator(s)	Final at software transition after launch	6.2 6.4 6.5 6.6 7.2.3	R		
SW-18	Subsystem High-Level Software Simulator(s), preliminary design version of GN&C programs	1 month prior to PDR	6.2 6.4 6.5 6.6	R		

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
SW-18	Subsystem High-Level Software Simulator(s), critical design version of GN&C programs	1 month prior to CDR	6.2 6.4 6.5 6.6	R		
SW-18	Subsystem High-Level Software Simulator(s), pre-launch version of GN&C programs	6 months prior to launch	6.2 6.4 6.5 6.6	R		
SW-19	Flight Software Releases	As generated Final at SWAR Updates until transition after launch	7.2.3	A		
SW-21	Software Development and Validation (SDV) Software Releases	Due with SDVF/FVMF/Training Simulator facility deliveries Updates s required and as-built at launch	7.6	A		
SW-23	SDVF/FVMF/Training Simulator Specification	Due with SDVF/FVMF/Training Simulator facility deliveries Update to as-built at launch	7.7 7.7	A		5
SW-24	SDVF/FVMF/Training Simulator Drawings, Wiring and Parts List	Due with SDVF/FVMF/Training Simulator facility deliveries Update to as-built at launch	7.7	A		5
IT-02	De-orbit Module and GSE Transportation Plan	Draft at CDR. Updates at PSR.	10.0	A		10
DM-01	De-orbit Module Specification	Due on contract award + 10 days Updates by PDR.	2.2.4 8.3	A		10
DM-02	De-orbit Module Verification Plan	Due on contract award + 10 days Updates at PDR and CDR.	2.3.1.2	A		10

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
DM-03	De-orbit Module Integration and Test Plan	Due on contract award + 10 days Updates at PDR and CDR.	8.2	A		10
DM-04	De-orbit Module Test and Verification Reports	Preliminary version due 1 month after completion of each test. Final version due prior to Robotic Servicing Mission PSR.	2.3.1.2 8.3	R		15 per test
DM-08	De-orbit Module Thermal-Mechanical Simulator User's Manual (DM-08)	Draft at PDR. Update at CDR.	8.3.2	R		20
DM-09	De-orbit Module Thermal-Mechanical Simulator Design Document	Draft at PDR. Update at CDR.	8.3.2	A		20
DM-15	De-orbit Module Electrical Simulator User's Manual	Due at DM electrical simulator delivery. Updates as required.	8.3.2	R		
DM-16	De-orbit Module Electrical Simulator Design Document	Due at DM electrical simulator delivery. Updates as required.	8.3.2	R		
OPS-01	Project Reference Data Base (PDB) Certification Plan	Due at CDR.	13.4	A	YES	20
OPS-02	Project Reference Data Base (PDB) Certification Reports	Due as defined in PRDB certification plan.	13.4	A		10 report per certification test
OPS-03	Reference Data Description Document	Due prior to start of DM element I&T.	13.4	A	YES	10

ID	Title	Schedule	SOW Ref	Action Required	CM Control	Quantity
OPS-04	Operations Handbook	Preliminary version by start of HRV I&T. Update at Robotic Servicing Mission MOR. Final version at Robotic Servicing Mission FRR.	13.4	R		50
OPS-05	De-orbit Module Constraints and Restrictions Document (CARD)	Due 6 months prior to start of HRV I&T.	13.4	A	YES	20
OPS-06	De-orbit Module Operations Limitations Document (OLD)	Due 6 months prior to start of HRV I&T.	13.4	A	YES	20
OPS-07	Flight System Description and Operations Manual	Preliminary version by start of HRV I&T. Update at Robotic Servicing Mission MOR. Final version at Robotic Servicing Mission FRR.	14.0	R		25
OPS-08	Training Scenarios and Training Course Materials	Due 1 year prior to Robotic Servicing Mission launch.	13.5	R		10
OPS-09	Flight Procedures Handbook	Preliminary version at Robotic Servicing Mission MOR. Final version at Robotic Servicing Mission FRR.	14.0	A		

Data Requirements Document (DRD)

for the

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

Table of Contents

1.0 INTRODUCTION

This document defines the requirements for the Hubble Space Telescope (HST) Robotic Vehicle (HRV) De-orbit Module (DM) deliverable data. Both formal and informal data types are addressed. Delivery schedule, action required, and quantity of hard copies is in the **Deliverable Item List (DIL)** of the contract. The DIL also identifies the deliverables that are subject to HST configuration control and shall conform to the **HST Configuration Management Plan (TBD).** The HST CM Office will make available the appropriate documentation format specified for controlled documents.

2.0 IDENTIFICATION

Each document is identified by one of the codes listed in Table 1 and are based on the subject content of the document.

Document Code	Subject Content
PM	Project Management
SA	Systems Assurance
SE	Systems Engineering
SW	Software
IT	Integration and Test
DM	De-orbit Module
OPS	Operations

Table 1. Document Code Identifiers

3.0 GENERAL REQUIREMENTS

The following sections describe general requirements for contractor-delivered documentation.

3.1 DISTRIBUTION

All data deliverables shall be delivered to the HST Library, Code 440, in accordance with the applicable paragraph of Section 4 with the exception of the financial data (**PM-06, PM-07, PM-09**). All deliverables shall include a delivery letter. The contractor shall send the Contracting Officer the original signed delivery letter. The contractor shall also send the Contracting Officer's Technical Representative (COTR) a copy of the delivery letter. The delivery letter copies can be hard copy or electronic copy with the original, signed version, to be scanned and provided in Portable Data Format (PDF).

Hard copies shall be sent to:

NASA/ Goddard Space Flight Center
HST Library, Code 440
Greenbelt, MD 20771

3.2 DATA DELIVERABLE FORMATS

The contractor shall use the content outline given for each document unless prior approval is received from the COTR to deviate from the required content. The contractor shall submit requests for content changes in sufficient time for adequate consideration by the affected recipients, generally two (2) weeks in advance of delivery.

3.2.1 Electronic Copies

Documents shall be compatible with Microsoft Word. Spreadsheets (tabular materials) shall be compatible with Microsoft Excel. Presentation materials shall be compatible with Microsoft PowerPoint. Additionally, the delivery of project schedules shall be compatible with Microsoft Project.

Engineering drawings generated and controlled by the Contractor, which are part of a contract deliverable, shall be delivered in PDF and native format on CD-ROM along with an index that includes the drawing number, title, and latest revision.

3.2.2 Hard Copies

Hard copies of documents are not normally required except for the Monthly and Quarterly Financial Management Reports. Quantity and distribution of the Financial Reports are delineated in the contract. All hard copies of documents shall be in accordance with the following general specification:

a. Finish size: 8 1/2 x 11 inches.
b. Pages are printed on both sides, avoiding blanks if possible.
c. Oversize pages are to be avoided but, if necessary, will be folded to 8 1/2 x 11.

It is preferred that documents be supplied in reproducible (i.e. non-bound) format, unless otherwise specified. If binding is required, it should be the most economical method commensurate with the size of the document and its intended use.

All documents must be paginated. Unless stated otherwise, all documents must have a "revision log" that identifies the dates and describes the update made to the each new version of the document.

Draft versions of documents need not conform to these specifications but they should be printed on 8 1/2 x 11 in. paper and be sufficiently clear to reproduce on office copiers.

3.2.3 Presentations

For review presentations, the COTR and the contractor should agree to arrangements for the materials supporting the event. Specifically, should transparencies be generated or will electronic overhead projection be provided; how many hard copies of the presentation materials should be generated; what electronic distribution list should be used etc. Note that these presentation materials are still also considered document deliverables and in addition to being materials supporting a review, they also must be delivered to the HST Program as specified in sections 3.2 and 3.3. Revision logs are not required for review presentations.

The technical reviews specified in this DRD are to be formal, electronic, technically oriented and conducted by the Contractor at the contractor's facility with a review board composed of experts appointed by the GSFC. Each review requires a review data package containing appropriate reference documentation for the review. A formal presentation shall be conducted with visuals, which summarize the review package contents. The review agenda and contents shall be mutually agreed to prior to proceeding with preparation of each review data package. At the conclusion of each review (technical and status) a report summarizing the review and listing all resulting action items shall be issued.

3.2.4 Photographs and Digital Images

All critical stages in the buildup, integration, and testing of flight hardware components, subsystems, and systems shall be documented photographically. All photo documentation will be captured digitally and saved in JPEG format to Photo CD with 3072 x 2048 pixel resolution. As a minimum, the following shall accompany the photo CD:

1. One set of index prints.
2. Description sheet for each CD, which contains the image number, date of photograph, description of each photograph, and additional keywords, if applicable.

When quick-turnaround photography is essential, the digital images can be stored in a designated image folder on the contractor's ftp site and the contractor shall notify the DMO that the images are available.

3.2.5 Video Documentation

In cases where video documentation of flight hardware buildup and integration is required, the required format is mini-DV format videotape. The Contractor shall provide one copy of each tape, clearly labeled with date(s) and detailed description(s) of the activity. If the tape covers several sequential activities that will not fit on the label, a description sheet should accompany the tape to provide sufficient detail.

3.3 DOCUMENT REVISIONS

3.3.1 CM-Controlled Documentation

Revisions to documents that are under HST CM control must comply with the requirements specified in the **HST Program Office Configuration Management Procedure (SCM-1020)** and the contractor's, HST-approved CM Procedure.

4.0 DATA ITEM DESCRIPTION

4.1 PROGRAM MANAGEMENT

4.1.1 PM-01 Management Plan

Description: The management plan provides NASA with a description of the Contractor's internal system and philosophy for managing the contract. It will describe the method in which the Contractor will create, maintain and give the HST Program access to their schedules.

Content: The project management plan shall clearly describe:

1. Project management strategy
2. Project management tools
3. Technical summary
4. Implementation approach
5. Schedules
6. Resources
7. Management reviews
8. Configuration Management & Document Management Controls
9. Performance Management & Assurance
10. Risk Management
11. WBS
12. Safety and Health

4.1.2 PM-02 Monthly Status Reports

Description: The monthly status reports, presented to the HST Program management team by the contractor, shall provide a project assessment of contract technical accomplishments, summary of program cost, schedule, and performance, as well as the status of key technical issues and near-term milestones. These reports shall provide a summary of the activities for the month, highlight issues/problems/concerns, and briefly summarize plans for the following month. Detailed supporting technical data should only be provided on an as needed basis.

The Contractor shall use HST milestone chart standards (electronic and otherwise) for any related schedule charts. Format can be obtained from the HST Scheduling Office. In addition, any changes to the baseline schedule needs to be highlighted on these charts in a manner that shows the original baseline and the new modified baseline, with an explanation for the change.

Content:

1. Schedule Status Reports
2. Technical Status Reports
3. Risk Mitigation Status
4. Performance Assurance Status
5. Contingency Release Status including Lien List (Cost, Schedule etc)
6. Action Item Status
7. One Month Look-ahead

8. One page fever chart summarizing critical status of above elements

4.1.3 PM-04 Weekly Activity Reports

Description: A report summarizing the significant activities and issues of the week.

Content: The report shall address staffing, schedule, progress, risk, technical issues and status and near-term milestones.

4.1.4 PM-06 Monthly Contractor Financial Management Reports (533M)

Description: The monthly Contractor financial management reports (533M) provide contractual expenditure data of cost incurred and estimates costs to complete. This information is necessary for the financial control and reporting required of this contract.

Content: Contract Clause(s) will define required content and format.

4.1.5 PM-07 Quarterly Contractor Financial Management Reports (533Q)

Description: The quarterly contractor financial management reports (533Q) provide contractual expenditure data of cost incurred and estimates costs to complete. This information is necessary for the financial control and reporting required of this contract and should include financial management on all subcontracts to the same level as for internal Contractor efforts.

Content: Contract Clause(s) will define required content and format.

4.1.6 PM-08 Earned Value Management System Implementation Procedures

Description: The Earned Value Management System (EVMS) implementation procedures shall describe the implementation of the EVMS system on the contract.

Content: The EVMS Implementation Procedures shall clearly document the integrated project management processes for the project. These procedures shall include but not be limited to the areas of organizing work, planning, budgeting, scheduling, work authorization, cost accumulation, measurement and reporting of cost and schedule performance, materials and subcontract handling, variance analysis and baseline control. These procedures shall flow down to major subcontracts as identified.

4.1.7 PM-09 Monthly Earned Value Management System Cost Performance Reports

Description: The Cost Performance Report (CPR) data will be used by NASA systems managers to: a) integrate cost and schedule performance data with technical performance measures, b) identify the magnitude and impact of actual and potential problem areas causing significant cost and schedule variances, and c) provide valid, timely project status information to higher management.

Content: Refer to clause 1852.242-75, Earned Value Measurement System (Mar 1999). The DD Form 2734/1 (Aug 96) shall be used in accordance with DoD Data Item Description DI-MGMT-81466.

The CPR shall provide Formats 1-5 down to WBS Level 3.

4.1.8 PM-10 Integrated Baseline Review (IBR) Package

Description: The Integrated Baseline Review (IBR) is a review of the Performance Measurement Baseline to ensure it captures the entire technical scope, schedule requirements, and has adequate resources.

Content: Refer to clause 1852.242-75, Earned Value Measurement System (Mar 1999). Contents provided for this review shall allow the project team to:

- Identify the risks inherent in the contractor's Performance Measurement Baseline (PMB).
- Verify the technical content of the PMB
- Evaluate the adequacy and accuracy of the related resources (budgets) and schedules

4.1.9 PM-100 Project Schedules

Description: Project schedules are used for planning, controlling, modeling and specifying work activities throughout the project life cycle. The objective of Project Scheduling include:

- Ensuring that all project work is planned and sequenced properly to effectively attain established need-by dates.
- Defining activity interfaces and constraints among all project participants, including equipment suppliers and subcontractors.
- Establish a baseline for controlling and measuring performance and providing visibility into work progress and early warning of problems.

A hierarchy of schedules is required to permit management and control of the work effort at a level of detail commensurate with the focus of management responsibility. This hierarchy of interlocking schedule baselines includes the Master, Intermediate, and Detailed Schedules.

- Master Schedule -- The Master Schedule represents the flow-up (summarization) of the subsystem detailed data which combines key program milestones, internal/external schedule dependencies, and controlled project trigger events
- Intermediate Schedules -- The Intermediate Schedules represent a summary of the detailed data contained within a Subsystem. Intermediate Schedules will be rolled-up into the Master Schedule.
- Detailed Schedules -- Detailed Schedule contains the backbone of events and activities that make-up the content of that subsystem. Detailed Schedules will be rolled-up into the Intermediate Schedules.

Detailed network diagrams shall be developed, delivered, and maintained containing each subsystem. These networks shall reflect the significant activitis in sufficient detail to permit adequate monitoring of work progress. A log of all changes to the logic flow will be maintained and reported monthly for both baseline and current schedules.

Agreed upon program milestones by both the contractor and project office will be control by the project office. All agreed upon Program Control Milestones (PCM) will be under Schedule Change Board control (SCB) and all changes to those milestones will be approved by the SCB with the approval of a Schedule Change Request (SCR). Each SCR will identify the impact of the change, cost & schedule, cause for making the change & work around and recovery options to be consider. Once submitted and approval by the Program SCB all changes are then authorized to be incorporated into the contractor baseline schedules. The monthly report shall include the current log of changes introduced during the reporting period and the current networks. Each activity will contain the following data:

- Description of activity
- Baseline start/completion date
- Current expected start/completion dates (early start/early finish – late start/late finish)
- Number of workdays required to complete the task
- Any changes in logic linkages
- Any changes in durations
- Amount of float/slack (in work days)
- WBS element
- Relationship to other (internal and external) activities and milestones

Activities in the detailed networks should generally be no more than twenty (20) working days in duration.

Scheduling Tool/Process: The HST program has standardized on an automated time phased Planning and Scheduling Software tool called Microsoft Project Professional that will be linked to a dedicated project sever that requires client access licenses. This approach will give team members and stakeholders the ability to view, update, and analyze projected information right from their WEB browser.

Schedule Control: Schedule Control provides early indications of potential problem areas and the means to reduce/minimize Schedule Risk throughout the total lifecycle of the project. Schedule control consists of data from standardized reporting mechanisms/metrics that will closely tie all items into a monthly reporting system.

Content: The following status and analysis reports will be provided to the HST Program:

- Master Level Logic Network: A logic network summarizing the Intermediate/Detailed networks using Microsoft Professional Planning Software

- Top Level Master Schedule: A Top Level schedule (chart) utilizing graphics software (Milestone Professional) that summarizes the Intermediate Level logic networks. This schedule must be suitable for a formal presentation.

- Detailed Level Logic Network: Detailed logic networks utilizing MS Project Professional software will be provided to the Project Office.

- Intermediate Level Summary Chart: An Intermediate level (Summary) schedule (chart) utilizing graphics software (Milestone Professional) that summarizes the detailed level logic networks. This schedule must be suitable for a formal presentation.

- Tabular Reports: Tabular reports sorted by subsystem and WBS that will reflect the same data as the detailed logic networks.

- <u>60-Day Window Report</u>: A report sorted by subsystem and dates, which list all activities expected to start or complete within sixty (60) days of the end of the month under review.

- <u>End-Item Window Report</u>: A monthly report, which reflects the float/slack for deliverable items and major milestones PCM as determined by the HRSDM Manager. This report shall provide a comparison of the current float to the baseline and prior three (3) months float. The contractor shall also supply an explanatory analysis for all changes that exceed the established Stoplight threshold.

- <u>Monthly Analysis</u>: Each monthly submittal shall begin with narrative sections for each major subsystem. This shall be followed by a float summary of all major elements showing three (3) months prior float status along with the current float position. Each section should address a brief description of current status and any existing or potential problems. A final section shall address the overall primary critical path status, as indicated by the detailed logic networks, and any work-around techniques being implemented or proposed to maintain schedule integrity.

- <u>Manufacturing Schedules</u>: Manufacturing schedules and status obtained from subcontractors and vendors are not required to be submitted with the monthly schedule submittal, however, they shall be supplied to the Project Office upon request.

- <u>Top Ten Critical Items</u>: The contractor shall submit monthly a list of the top ten critical items or milestones.

4.1.10 PM-33 Configuration Management Plan

<u>Description</u>: The configuration management plan establishes the Contractor's general approach, policies, and procedures for managing configuration. The Plan shall assure the HST Program that all procured and manufactured equipment, software, and documentation vital to the development of the DM shall remain well described and accounted for even after modification, enhancement or replacement. It shall be consistent with the HST Program configuration management procedures and policies.

<u>Content</u>: The Contractor shall provide the appropriate information necessary to achieve quality configuration management .

4.1.11 PM-35 System Requirements Review

<u>Description</u>: The System Requirements Review (SRR) is a presentation to a NASA-led Review Team to demonstrate that the DM Contractor has fully defined the DM system-level requirements. The HST Program will approve necessary modifications to this package.

<u>Content</u>: The SRR shall include, but not be limited to, the following:

1.0 System Requirements
2.0 System and subsystem conceptual architectures
3.0 Documentation
4.0 Safety
5.0 Performance Assurance
6.0 Facilities

7.0 Operational Concepts

The SRR objectives include:

a. Establish the basis for subsequent design and verification test activities by identifying formal DM and operation requirements and their pedigree.

b. Confirm that the DM-level requirements meet the mission objectives

c. Confirm that DM-level specifications are sufficient to meet the project objectives.

4.1.12 PM-37 Preliminary Design Review

Description: The preliminary design review (PDR) is a presentation to a NASA led Review Team to demonstrate that the DM preliminary design meets all system requirements with acceptable risk. It demonstrates that interfaces have been properly identified and verification methods have been satisfactorily described. It also establishes the basis for proceeding with detailed design and fabrication and test. The PDR will review all DM systems and requirements, resource allocations, verification plans, and preliminary ICDs. The PDR shall include a Presentation Package and a Preliminary Design Description Document that contains detail-supporting data for the presentation package.

Content: The PDR shall include, but not be limited to, the following:

1. System design
2. Interface Requirements Documents
3. Interface Control Documents
4. Fault Detection and Handling (FDH) during time critical events
5. Problem areas and their resolution
6. Open items
7. Safety and health
8. Flight operations
9. Analyses and trade off studies
10. Preliminary test plans (environmental and functional)
11. Performance assurance
12. Packaging and production
13. Schedules
14. Configuration management/documentation
15. Resources
16. Long lead time hardware and software
17. Facilities
18. Technology readiness
19. Advanced development decisions
20. Logistics
21. Risk management

The PDR objectives include:

a. Ensuring that all system requirements have been allocated, the requirements are complete, and the flow down is adequate to verify system performance.

b. Showing the proposed design approach is expected to meet the functional and performance requirements and permit final design decisions to be made.

c. Showing sufficient maturity in the proposed design approach to proceed to final design.

d. Showing that the design is verifiable and that the risks have been identified, characterized, and mitigated where appropriate.

e. Identifying potential technical problems and corrective actions; dispositioning comments and recommendations; and defining action items and closeout plans.

f. Updating programmatic assessment of resources and schedule and identifying problem areas.

g. Demonstrating the basis for proceeding with the purchase of long-lead items.

4.1.13 PM-39 Critical Design Review

Description: The Critical Design Review (CDR) is a presentation to a NASA led Review Team to present detailed DM system designs. It allows for the final DM requirements, resource allocations, verification plans, ICDs, and detailed designs (including simulators required to verify designs) to be presented, discussed, modified (if necessary) and approved. It discloses the complete system design in full detail, ascertains that technical problems and design anomalies have been resolved, and ensures that the design maturity justifies the decision to initiate Flight Unit fabrication/manufacturing, integration and verification of mission hardware and software. The CDR shall include a Presentation Package and a Design Description Document that contains detail/supporting data for the presentation package.

Content: The CDR shall include, but not be limited to, the following:

1.0 Subsystem and system design
2.0 System, subsystem and component specifications
3.0 Interface Control Documents
4.0 Problem areas and their resolution
5.0 Open items
6.0 Safety
7.0 Analyses and trade off studies
8.0 Software systems
9.0 Design margins
10.0 Test plans (environmental and functional)
11.0 Performance assurance
12.0 Flight operations
13.0 Packaging and production
14.0 Schedules
15.0 Configuration management/documentation
16.0 Resources
17.0 Facilities
18.0 Technology readiness
19.0 DM Integration and Test Requirements
20.0 Logistics (including Transportation Plans)

The CDR objectives include:

a. Establishing the acceptability of the DM final design so that manufacturing can be formally initiated and baseline engineering documentation defined.

b. Ensuring that the "build-to" baseline contains detailed hardware and software specifications that can meet functional and performance requirements.

c. Ensuring that the design has been satisfactorily audited by production, verification, operations, and other specialty engineering organizations.

d. Ensuring that the production processes and controls are sufficient to proceed to the fabrication stage.

e. Establishing that planned Quality Assurance (QA) activities will establish perceptive verification and screening processes for producing a quality product.

f. Verifying that the final design fulfills the specifications established at PDR.

g. Identifying potential problems, corrective actions, and open items (including disposition of actions from PDR) for follow-up and close out by responsible parties.

4.1.14 PM-40 Mission Operations Review

Description: The contractor shall contribute to a GSFC-led Mission Operations Review (MOR) at GSFC. The MOR is a technical review that covers all mission-oriented operations including robotics, spacecraft, and ground systems operations. The overall design and status of the ground and flight systems shall be presented to assure that all requirements will be met.

MOR Typical Agenda:

1.0 Mission Operations Requirements
2.0 Facilities
3.0 Ground System
4.0 Staffing
5.0 Spacecraft Overview
6.0 Schedules
7.0 Procedures (nominal and procedural)
8.0 Documentation
9.0 Risks

MOR Typical Content:

- Operational interfaces between the ground system and flight system (identify operational trade-offs, signal link margins, constraints, and modes of operation including safe modes)
- Mission integration of pre-launch test planning (identify all planned tests between the flight segment and the ground system)
- Identification of the relationship between planned ground system software releases/capabilities and planned tests with the flight segment

- Identification of plans and status for flight operations team and instrument/technology operations preparations
- Overall schedule and status (include documentation status for spacecraft operations concept, ground system requirements, flight operations and contingency plans and Interface Control Documents)
- Mission, technology, spacecraft, flight software, and ground system overviews
- Flight software maintenance approach
- Flight operations team build up and training plans
- Pre-launch test plans including: RF and ground system compatibility tests, data flow and end-to-end tests, simulations and exercises, launch site tests
- Launch and early orbit overview including deployment activities and coverage
- In-orbit checkout overview
- Project database and procedure development
- Spacecraft and operations constraints
- Spacecraft subsystem level activities
- Mission planning and scheduling
- On-board data memory management
- Real-time operations including: health and safety monitoring, safe mode operation
- Ground system requirements and development status
- Mission readiness testing
- Preliminary list of all launch-critical facilities and functions

4.1.15 PM-41 Test Readiness Review

Description: The Test Readiness Review (TRR) is a presentation to a NASA led Review Team to present status of the DM systems prior to start of testing. It is a technical review that establishes functional compliance with all technical requirements prior to exposure to environmental conditions. The TRR is a major milestone in establishing functional capabilities prior to environmental exposure and is therefore a technical baseline of functional characteristics of the system. Also, functional anomalies and their resolution will have been reviewed and formally closed out, including disposition of actions from the CDR. It also establishes approval of the formal test plans to be used for subsequent environmental testing.

Content: The TRR shall include, but not be limited to, the following:

1.0 Test plans and procedures
2.0 Test support requirements and status

- 2.1 Personnel
- 2.2 Facilities
- 2.3 GSE
- 2.4 ASE
- 2.5 Software
- 2.6 Elements in database
- 2.7 Instrumentation

3.0 Documentation status
4.0 Functional and environmental test history of systems and subsystems
5.0 Anomalies and their resolution
6.0 Deviations and waivers
7.0 Open items and plans for close out
8.0 Safety
9.0 Performance Assurance
10.0 Schedules

The TRR objectives include:

a. Establishing the system readiness to function during environmental exposure, and permitting the Contractor to proceed with the environmental test program.

b. Confirming that in-place test plans meet verification requirements and specifications.

c. Confirming that sufficient resources are allocated to the test effort.

d. Examining detailed test procedures for completeness and safety during test operations.

e. Determining that critical test personnel are test-and-safety-certified.

f. Confirming that test support hardware and software is adequate, pertinent and verified.

4.1.16 PM-42 Operations Readiness Review

Description: The contractor shall contribute to a GSFC-led Operations Readiness Review (ORR) at GSFC. The ORR is used to present details on the readiness for operations. It is a formal review to determine the state of readiness to support the HRV operations functions. The ORR examines the actual system characteristics and the procedures used in its operation, and demonstrates that all flight and ground hardware, software, personnel, procedures, and user documentation reflect the deployed state of the system accurately.

Content: The ORR shall include, but not be limited to, the following:

1.0 Liens from MOR
2.0 Mission Operations Requirements
3.0 Facilities
4.0 Ground System
5.0 Staffing
6.0 Spacecraft Overview
7.0 Schedules
8.0 Procedures (nominal and procedural)
9.0 Documentation
10.0 Risks

The ORR objectives typically include:

a. Establishing the state of readiness of the HRV operations and supporting flight operations and HRV systems.

b. Establishing that the system is ready to transition into an operational mode through examination of available ground and flight test results, analyses and operational demonstrations.

c. Confirming that the system is operationally and logistically supported in a satisfactory manner considering all modes of operation and support (normal, contingency and unplanned.)

d. Establishing that operational documentation is complete and represents the system configuration and its planned modes of operation.

e. Establishing that the training function is in place and has demonstrated capability to support all aspects of system maintenance, preparation, operation, and recovery.

f. Identifying problems, corrective actions, and open items for close out by responsible parties.

4.1.17 PM-43 Pre-Shipment Review

Description: The Pre-Shipment Review (PSR) is a presentation to a NASA led Review Team to present status of the DM prior to shipment. It establishes readiness to ship flight hardware. The technical review shall concentrate on past system performance during functional and environmental testing. Necessary modifications require the approval of the HST Program. The contractor shall perform a PSR prior to the shipment of any flight hardware.

Content: The PSR shall include, but not be limited to, the following:

1.0 Test history (functional and environmental)
2.0 Interface verifications
3.0 Anomalies and corrective actions
4.0 Deviations and waivers of specification requirements
5.0 Open items and plans for close-out
6.0 Potential problems/concerns
7.0 Documentation status
8.0 Performance assurance
9.0 Safety
10.0 Shipping plans
11.0 Support requirements for DM shipping through launch

4.1.18 PM-47 Risk Management Plan

Description: The Risk Management Plan documents plans to identify and mitigate risks, and to measure the effectiveness of implemented risk management strategies.

Content: The risk management plan should clearly describe:

- Risk identification approach
- Risk mitigation philosophy
- Risk mitigation plan

4.2 SYSTEMS ASSURANCE

The system assurance deliverables are described the **HRSDM Project Mission Assurance Requirements (SMR-5000)**. They are:

SMR-5000 DID 1-1: Mission Assurance Plan

SMR-5000 DID 1-2: End Item Data Package

SMR-5000 DID 2-1: Quality Manual

SMR-5000 DID 3-1: System Safety Program Plan

SMR-5000 DID 3-2: Safety Assessment Report (SAR)

SMR-5000 DID 3-3: Safety Data Package

SMR-5000 DID 3-4: Hazard Control Verification and Tracking

SMR-5000 DID 3-5: Ground Operations Procedures

SMR-5000 DID 3-6: Safety Nonconformance Requests

SMR-5000 DID 3-7: Orbital Debris Assessment

SMR-5000 DID 12-1: Polymeric Materials and Composites Usage List

SMR-5000 DID 12-2: Inorganic Materials and Composites Usage List

4.3 SYSTEMS ENGINEERING

These deliverables are prepared by the DM Contractor for both internal and external interface aspects of the De-orbit Module element.

4.3.1 SE-01 Systems Engineering Plan

Description: The systems engineering plan shall provide NASA with a complete detailed description of the Contractor's approach to performing DM systems engineering. It shall demonstrate a thorough understanding of HST Robotic Vehicle (HRV) goals and objectives, coordinate the proper interaction within and among all DM elements, and demonstrate a thorough understanding of technical issues and requirements.

Content: The plan shall contain the following information:

- Organization diagram with reporting relationships within and outside of the systems organization
- Specific internal methods, policies and procedures to be implemented
- Methods for resolving disputes
- Control of technical resources (mass, power, data storage, etc.)
- Formal review schedules and processes
- Action item tracking and control system

4.3.2 SE-02 Electromagnetic Compatibility (EMC) Control Plan

Description: The Electromagnetic Compatibility (EMC) Control Plan provides the overall approach and requirements of the EMI (Electromagnetic Interference) control program and defines the general requirements that will insure compliance of the hardware with the mission EMC requirements within the DM.

Content: The EMC Control Plan shall define the overall approach, planning, and design criteria to ensure compatible operation of the HRV. This plan shall provide the EMC requirements and management organization procedures for the prime contractor, subcontractors, vendors, and hardware as it relates to EMC control. The plan shall identify the particular requirements in the design area for bonding, grounding, and shielding to control radiated and conducted emissions and susceptibility to specified EMI/EMC levels. This plan shall be traceable to GEVS-SE and requires approval by the government.

4.3.3 SE-03 Fault Protection Requirements Document

Description: The Fault Protection Requirements Document (FPRD) provides requirements for all reliability analyses, fault tolerance requirement assessments, failure modes and effects analyses, and related or supporting engineering information necessary to ensure DM risk containment.

Content: The FPRD shall include objectives, level of the analysis, ground rules, functional description, functional block diagrams, reliability block diagrams, bounds of equipment analyzed, reference to data sources used, identification of problem areas, single-point failures, recommended corrective action, and work sheets as appropriate for the specific analysis being performed.

A Critical Items List shall be included, containing item identification and retention rationale. Appropriate retention rationale may include design features, historical performance, acceptance testing, manufacturing product assurance, elimination of undesirable failure modes, and failure detection methods.

4.3.4 SE-04 Fault Protection Description Document

Description: The Fault Protection Description Document (FPDD) describes all reliability analyses, fault tolerance requirement assessments, failure modes and effects analyses, and related or supporting engineering information necessary to ensure DM risk containment.

Content: The FPDD shall provide specific references necessary to implement the requirements specified in the Fault Protection Requirements Document (FPRD). The FPDD shall provide a description of the autonomous system fault protection for the Spacecraft. This document shall describe how the Spacecraft fault protection ensures the health, safety, and system integrity of HRV and HST, and provides protection against damage to HST in the presence of anomalous conditions. This document shall describe the architecture of the fault protection system and the algorithms that comprise it. The document shall provide an overview of fault-protection capabilities provide by the DM. The document shall describe all reliability analyses, fault tolerance requirement assessments, failure modes and effects analysis, and related or supporting engineering information necessary to ensure DM risk containment.

4.3.5 SE-05 Math Models Data Package

Description: The Math Models Data Package provides the necessary description documents for the electrical, mechanical, and thermal math models that represent the simulated performance of the DM.

Content: The content of each model is described below.

4.3.5.1 Electrical Models

The contractor shall deliver a full set of electronic system schematics. The HRV electrical models provided by Contractors to the HST Program shall be systems level representations of the De-orbit and Ejection Module Electrical Power Systems. Each model shall include all HRV to HST and Deorbit Module to Ejection Module electrical interfaces. Each model shall be the same as or derived from models used by HRV Contractors in the design, development, and verification of HRV electrical systems. The provided models shall be in OrCAD PSpice for inclusion by the HST Program in the HST system level electrical model.

4.3.5.2 GN&C models

The Contractor shall create and deliver mathematical models of all DM GN&C elements including hardware and software.

4.3.5.2.1 GN&C Model Requirements

The Contractor shall deliver a mathematical model for each GN&C-specific flight software function (i.e., Attitude Determination and Control, Absolute Orbit Determination, Relative Navigation, Relative Control). Each mathematical model shall contain detailed description of the algorithms used by the software.

The Contractor shall deliver a mathematical model for each DM GN&C hardware component. The mathematical specification shall be valid for all possible operating conditions on the DM. An assessment shall be made of the fidelity of each model.

4.3.5.2.2 GN&C Model Validation

The GN&C models shall be validated via correlation with test results. The correlation required shall be documented and provided along with a comparison of model predictions with test results.

4.3.5.2.3 GN&C Documentation and Data Files

The Contractor shall deliver a report documenting the GN&C mathematical models. The report shall include any and all supporting data files and their descriptions in human-readable, plain ASCII text.

4.3.5.2.4 GN&C Model Delivery Frequency

GN&C models and accompanying documentation shall be delivered at a frequency and schedule to be negotiated with the HST Program. In general it is expected that models shall be delivered at specific milestones in the DM development schedule and at unscheduled times when design and model updates and changes warrant.

4.3.5.3 Mechanical Models

The Contractor shall create and provide a DM Finite Element Model (FEM). The following is a summary of requirements most appropriate to the delivery of the DM models.

4.3.5.3.1 Finite Element Model Requirements

<u>Description:</u> Provide FEM of the HRV components to support coupled launch vehicle and HST stability analyses.

<u>Content:</u> The structural models shall be derived from detailed models used in the design, development, and verification of HRV components. The first lateral and torsion modes determined from these simplified models shall agree within ± 3%, with those predicted by the more detailed models. Agreement shall be determined by comparing natural frequency and modal effective weight properties. In addition, the output data from the detailed model shall be supplied for comparison to the simplified model output data.

The derived models shall be dynamically reduced to Craig-Bampton (or equivalent) form of up to 600 degrees of freedom for each major HRV component. Transformation matrices shall be included to allow for recovery of critical physical responses in the component, as well as to allow for application of applied loads, pressures, and temperatures for system level assessment. All FEM 's shall be capable of dynamic and thermal distortion analysis under all expected load conditions, and accurately track motion on critical elements due to structural temperature changes.

The model shall be able to predict motion of major mass items and points of mechanical disturbance. The reduced model shall represent modes below 200 Hz. Data shall be transmitted by electronic media using mutually agreed upon media and format.

The structural analysis shall include considerations of all relevant structural elements, with loads, vibrations, resonant freq, shock, and acoustics for all mission phases, and all flight hardware shall have a detailed stress analysis. If FEA is used, sufficient mesh fidelity shall be used to account for high stress gradient regions. Classical hand stress analysis shall be used in conjunction with FEA or separately, particularly in areas of complex load geometry such as joints and fittings.

4.3.5.3.2 Finite Element Model Validity Checks

The Contractor shall include, with delivery of the model, computer runs and data checks to confirm the mathematical validity of the model.

4.3.5.3.3 Deliverable NASTRAN Model Documentation and Data Files

The NASTRAN model documentation and data files shall be delivered on one or more compact disks to the HST Program.

Model documentation shall be in Microsoft Word compatible format, and shall include:

- A description of the model, any special modeling features used, and rationale for the modeling methodology
- Detailed plots of the NASTRAN model clearly showing all grid points, element numbers and connectivity, element types, and attachment points with respective degrees-of-freedom
- A summary of key nodes/elements associated with optical elements, sub-components, and interfaces.
- A list of all material properties used in the model and a source for those values
- Mechanical and functional description of all mechanisms in the DM, whether they are modeled or not shall be identified
- A copy of any mass and stiffness calculations used in generating the input data for the model and a description of how the masses were distributed throughout the structure
- Identification and description of all parts which are fracture critical based on mission success
- Summaries of all analyses performed, with appropriate cross-references to NASTRAN models and design drawing numbers

The following math model data files shall be delivered:

- A copy of the pre/post-processing model file (i.e. FEMAP, PATRAN, IDEAS, etc.) associated with the finite element model.
- Copies of NASTRAN input (.dat/.bdf) files and results (.f06).

4.3.5.3.4 Solid Model

The Contractor shall create DM solid models in either a native Pro/Engineer format or a Standard for the Exchange of Product Model Data (STEP) export format to the HST Program. Solid model conversion results shall be crosschecked at least once per design cycle.

4.3.5.3.5 Model Delivery Frequency

Mechanical models and accompanying documentation shall be delivered at a frequency and schedule to be negotiated with the HST Program. In general it is expected that models shall be delivered at specific milestones in the DM development schedule and at unscheduled times when design and model updates and changes warrant.

4.3.5.4 Thermal Models

The contractor shall create and provide to the HST Program a mathematical thermal model along with any associated geometric surface models.

4.3.5.4.1 Thermal Model Requirements

The contractor shall provide the DM geometric model as a Thermal Synthesizer System (TSS) Geometric model and a thermal math models in SINDA 85 format. DM Reduced Geometric Math Model (RGMM) and the Reduced Thermal Math Model (RTMM) shall be documented in a User's Manual. The User's Manual shall have sufficient documentation and figures of the model shall be provided for independent analysis runs. All RTMM special programs for control algorithms such as heater logic, VCHP logic, CPL/LHP logic et al shall be provided as part of model delivery. The deliverable RGMM/RTMMs of the DM shall be correlated to the detailed thermal models within 2°C for critical node/components.

- The thermal math models shall demonstrate that all DM thermal requirements are met for all modes of operation.
- The thermal math models shall be capable of steady state and transient prediction over all expected temperature ranges.
- The thermal math models shall be capable of calculating the heat transferred within the DM and exchanged with attached hardware (e.g., the HST, the Ejection Module).
- The thermal models shall include any HST Program provided thermal models and associated geometric surface models of HST provided hardware.
- All thermal material and optical properties shall be consistent with the material and optical properties databases maintained by the HST Programs. The contractor shall document any properties unique to the DM (i.e. not in the project database).
- Thermal models must contain comprehensive comments within the listings. Descriptions of nodes, masses, materials, thermo-physical and thermo-optical properties, conductive and radiative couplings, key assumptions, heater locations, power dissipations, should be evident within the model listings. All geometric surface models used to provide radiation interchange factors for the detailed thermal math models should also be similarly commented. Input and output units shall be clearly specified.

4.3.5.4.2 Thermal Model Validation

The model shall be validated via correlation with thermal test results. The correlation required shall be documented and provided along with a comparison of model predictions with test results.

4.3.5.4.3 Thermal Model Documentation and Data Files

The contractor shall provide a report describing the DM thermal design and the RGMM/RTMM. The thermal model documentation and data files shall be delivered on one or more compact disks to the HST Program. Thermal model documentation shall be in Microsoft Word compatible format. Included in this report shall be the following:

a. Provide the following temperature limits:

- Temperature limits necessary for adequate operational performance.
- Temperature limits for which catastrophic failure occurs.
- Temperature limits for non-operational shipment or storage.

b. Provide the following temperature gradient limits:

- The temperature gradient constraints required for the spacecraft-mounting (conductive sink) surfaces and the rationale for the requirements.
- The temperature gradient constraints required between identified spacecraft radiative surfaces (radiative sink) and the rationale for the requirements.

c. Provide the following power dissipation information:

- An accurate definition of the power required and the power dissipated as heat in the parts and/or electronics subassemblies is required for the following conditions:
  - Operating flight steady-state conditions.
  - Non-operating flight steady-state heater dissipation at minimum bus voltage, Vdc (TBR).
  - Maximum transient (peak) flight operating power duration and frequency.
- The location of the dissipated power (as heat) is to be identified to its corresponding part and/or electronics subassembly level and is to be related to the analytical model node number(s).
- The power, control bank (ON/OFF) and the location (related to analytical model node number) are required for any thermal control heaters both operational and survival that are placed to maintain required temperatures. In addition, any heater logic required for control shall be provided in the thermal model.

d. Provide the following mechanical properties:

- The DM assembly weight, size, and volume must be given with the relevant uncertainties.
- An interface control drawing should be presented giving external dimensions for reference to indicate the size and volume. The analytical model node numbers should be located on a sketch for reference.
- In addition, the surface area, materials, and coatings of each node in the models must be listed.

e. Provide the surface finishes and optical properties data:

DM materials and surface finishes, with related total hemispherical emittance and UV absorbance should be identified for the analytical model surfaces/nodes.

f. Miscellaneous:

Any other important thermal data required to use or understand the analytical thermal model should be provided.

4.3.5.4.4 Model Delivery Frequency

Thermal models and accompanying documentation shall be delivered at a frequency and schedule to be negotiated with the HST Program. In general it is expected that models shall be delivered at specific milestones in the DM development schedule and at unscheduled times when design and model updates and changes warrant.

4.3.6 SE-06 Inputs to De-orbit Module to HST ICD

THIS IS AN HST PROGRAM DOCUMENT. This document will be jointly developed by the Contractor and the HRV development team.

4.3.7 SE-07 De-orbit Module to Ejection Module ICD

Description: The De-orbit Module to Ejection Module ICD is used to define the interface of the DM with EM.

Content: Specific requirements will include, but not be limited to, allocations for HRV mass, volume, power, and area. HRV specific requirements such as alignment budgets may also be captured in the ICD. The fuel budget for pursuit, proximity operations, capture, servicing, and disposal shall be included in this document.

Specific interfaces include, but are not limited to:

- Electrical Interfaces
    - Power
    - Command and Data Handling
- Mechanical/Structural interfaces.
    - Environmental interface
    - Assembly, integration and test interfaces
    - Modeling interfaces
- Thermal interfaces
    - Environmental interface
    - Assembly, integration and test interfaces
    - Modeling interfaces
- Optical interfaces.
    - Camera optics interface.
- Robotic/servicing interfaces and keep-out zones

4.4 GN&C

4.4.1 GNC-01 GN&C Planning Document

Description: This document shall describe the Contractor's overall approach to designing, building, testing, and integrating the GN&C system for the DM. It shall also identify the critical technologies requiring development for successful GN&C system delivery.

Content: The document shall contain the following information:

- Organization diagram of the GN&C team with reporting relationships within and outside of the organization to include any and all subcontractors responsible GN&C components
- Schedule for delivery of key GN&C components, algorithms, software prototypes, reports, and analyses
- Configuration control plan
- Policies on carrying design margin
- Listing of units and conversions to be used for all key quantities
- Critical technologies identification and developmental approach
- High-level plan for critical GN&C functionality (relative navigation and control; level of autonomy; fault detection isolation, and recovery; abort; safe hold; plume impingement avoidance; etc.)

4.4.2 GNC-03 DM Mass Properties

Description: This document shall estimate the DM mass properties.

Content: The document shall contain the DM mass, inertia matrix with respect to the specified DM coordinate system, and identification of the principal DM axes. The uncertainties shall be quantified. In addition to the document, this information shall be made available, with units listed, in a plain ASCII text file suitable for input to MATLAB, C code, with updates published every 2 months and at unscheduled times as design changes warrant.

4.4.3 GNC-04 GN&C Hardware Specifications

Description: The GN&C Hardware Specifications will specify all necessary performance parameters of the EM propulsion and attitude actuation systems required by the DM during the pursuit, proximity operations, capture, servicing, and EM jettison phases of the mission.

Content: The Hardware Specifications shall include all performance parameters required by the DM of the EM including: total delta-velocity required; minimum impulse bit; thrust range, precision, and accuracy; torque range, precision, and accuracy; and momentum storage.

4.4.4 GNC-05 ADCS Performance Analysis

Description: ADCS Performance Analysis shall provide error budget analysis for the DM ADCS system. It shall present expected performance of ADCS in terms of accuracy and uncertainty based on realistic simulation to include modeling of appropriate sensors and actuators.

Content: The document shall contain a description of the simulation and analysis performed, justification for the error budget, consideration of most probable anomalous conditions, and plots and statistics of expected ADCS performance.

4.4.5 GNC-06 Trajectory Analysis and Maneuver Planning Document

Description: The Trajectory Analysis and Maneuver Planning Document describes the trajectory of the HRV, EM, and DM through all phases of the mission. It describes all planned maneuvers and contingencies.

Content: *This document shall be developed jointly with the HST Program Office.* The document shall contain a detailed plan for the trajectory of each spacecraft throughout the mission. Ephemeris data will be published in the document and electronically in plain ASCII tabular format. Analysis of expected dispersions from nominal trajectory shall be presented with consideration given to expected ADCS and Orbit Determination errors as well as expected propulsion error sources. The maneuver plan shall contain the fuel budget for each module.

4.4.6 GNC-07 Orbit Determination Performance Analysis

Description: The Orbit Determination Performance Analysis describes the expected performance of the DM on-board orbit determination system.

Content: The document shall contain an error budget analysis and justification for the expected levels of error from all likely sources. The document shall also contain results from realistic simulations that demonstrate the performance of the Orbit Determination system.

4.4.7 GNC-08 Propulsion Design Analysis

Description: This document shall describe the Contractor's design approach in developing a propulsion system that meets the customer requirements.

Contents: This document shall include design trades studies and options, design recommendations that meet the customer requirements, component layout and descriptions of components, development status of components, and propellant budget analysis. The document shall also include mechanical, thermal and electrical ICD information.

4.4.8 GNC-09 Propulsion Fluid Analysis

Description: This document shall describe detailed analyses of the fluid mechanics/dynamics of the propulsion system.

Contents: This document shall contain, as a minimum, pressure drop analysis, thruster modeling, tank slosh analysis, pressure surge (waterhammer) analysis and plume impingement analysis.

4.4.9 GNC-10 Propulsion System Structural Analysis

Description: This document shall describe structural analyses specific to the propulsion system, including any pressure vessel fracture control analysis.

Contents: This document shall contain detailed structural analyses of the propulsion components, including propulsion lines and brackets. For pressure vessels, the contractor shall include fracture control analysis and show how the design complies with the range safety.

4.4.10 GNC-11 Propulsion System Thermal Analysis

Description: This document shall describe thermal analyses specific to the propulsion system.

Contents: This document shall contain detailed thermal analyses of the propulsion system to demonstrate the design can meet the overall thermal requirement. The contractor shall include expected thermal environment of the propulsion system, required thermal hardware and heater power budget information.

4.4.11 GNC-12 Relative Control Performance Analysis

Description: The Relative Control Performance Analysis describes the expected performance of the DM Relative Control performance during the pursuit, proximity operations, and capture phases. The document shall describe all expected sources of errors and quantify their significance.

Content: The document shall contain an error budget analysis and justification for the expected levels of error from all likely sources. The document shall also contain results from realistic simulations that demonstrate the performance of the Relative Control system.

4.4.12 GNC-13 Relative Navigation Performance Analysis

Description: The Relative Navigation Performance Analysis describes the expected performance of the DM Relative Navigation performance during the pursuit, proximity operations, and capture phases. The document shall describe all expected sources of errors and quantify their significance.

Content: The document shall contain an error budget analysis and justification for the expected levels of error from all likely sources. The document shall also contain results from:

- realistic, sensor-hardware-in-the-loop simulations
- Monte Carlo type software-only simulation

that demonstrate the performance of the Relative Navigation system.

4.4.13 GNC-14 Coupled Motion Analysis

Description: The Coupled Motion Analysis describes the interaction between the motion of the spacecraft under control, be it the HRV or the HRV and the HST (post-capture), and the GA.

Content: *This document shall be developed jointly with the HST Program Office.* The document shall contain the development of the dynamical models for the GA, the HRV, and the HST. The document will contain results showing:

- disturbances induced on the GA due to HRV control
- disturbances induced on HRV due to the GA control
- results and limitations of coordinated HRV/GA control

4.4.14 GNC-15 Plume Impingement Analysis

Description: The Plume Impingement Analysis describes the constraints imposed on the HRV vehicle control to avoid thruster plume impingement on HST. The document also describes the expected minimal plume impingement for several reference cases including a stable HST and a tumbling HST.

Content: The document shall contain a mathematical description of the HRV controller constraints and the thruster plumes. It shall also contain a statistically meaningful set of simulation results characterizing the amount of expected plume impingement on HST to include the cases of a stabilized HST and a tumbling HST.

4.4.15 GNC-17 GN&C Test Plan

Description: The Test Plan provides a detailed description of how the Contractor shall execute, in a cost-effective manner, the testing activity to validate that the DM GN&C system conforms to the requisite performance specifications including environmental exposures (radiation, thermal vacuum, thermal balance, vibro-acoustic, shock, etc.).

Content: The content shall include:

- Test objectives
- Roles and responsibilities of the members of the test team
- Test requirements, including requirements definition and management, data reduction/analysis and management, reporting of discrepancies, and rework and retest provisions
- Security, safety, and precautionary provisions to safeguard the DM and personnel
- Facility cleanliness and contamination control provisions
- DM GN&C testing flow/description, with facilities, GSE, configurations, and list of procedures
- Test equipment requirements, and facilities including descriptions with capabilities

- Test program description, including test sequence, objectives of each test, preparations required, facilities, GSE, configurations, and list of procedures
- Facility planning and modification plans

4.4.16 GNC-18 GN&C Test Procedures and Results

Description: The GN&C Test Procedures and Results document describes the step-by-step procedures and results for each test included in the GN&C Test Plan.

Contents: The document shall include:

- Time, date and location of the test
- Model and serial numbers of all GN&C hardware involved in the test
- Name of the technician(s) executing the test and recording data
- Electronic delivery of all recorded data
- Acceptable ranges for all quantities
- Description and release of any post-processing data reduction and visualization tools
- Detailed test procedures
- Test results
- Observational notes made during the testing

4.4.17 GNC-19 GN&C Acceptance Test Report

Description: This report summarizes compliance with GN&C specification requirements and/or provide a summary of testing and analysis results, including conformance, nonconformance, and trend data.

Content: The content shall include:

- Validation Report: Provide after DM GN&C validation activity. For each analysis activity the validation report shall describe the degree to which the objectives were accomplished, how well the mathematical model was validated by the test data, and other significant results.
- System Performance Validation Report: Compare hardware/software specifications with the verified values (whether measured or computed).

4.4.18 GNC-21 GN&C Requirements Specification

Description: The GN&C Requirements Specification describes the requirements on each element of the DM GN&C system.

Contents: The document shall include:

- Detailed, outline-style listing of each GN&C element requirement
- A traceability matrix that maps each GN&C requirement to a system or sub-system (higher level) requirement from which it is derived.

4.5 SOFTWARE

4.5.1 SW-01 Software Management Plan

Description: This document describes the Contractor's overall systematic approach to managing the processes used in the design, development, testing (all phases), documentation, configuration management, risk management, assurance, and delivery of the Flight and Software Development & Validation (SDV) software Elements.

Content: The Software Management Plan shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Descriptions NASA-DID-M000, and –M400. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SMP approach such as MIL-STD-498 (DID DI-IPSC-81427A) or IEEE standards.

In addition to the content required by NASA-DID-M000, include the following topics as well:

a) A description of practices, tasks, and activities performed as a basis for Contractor effort and schedule determination.

b) A description of all subcontractor management and monitoring.

c) A description of the software development organization, including the organization chart, and a description of how the software personnel structure is integrated into the overall HRV development organization.

d) An identification of the deviations from the standard life cycle to accommodate the integration of commercially acquired software. Specifically include justification for less than thorough testing of COTS software.

e) An identification of the deviations from the standard life cycle to accommodate the integration of reuse software. Include specific justification that the reuse is applicable and preferable.

f) A description and justification of the criticality classification and type for each software component.

g) A justification of the selected software language(s) and development methodologies.

h) A specification of software protection against vandalism, viruses, unauthorized access, and disaster risks.

i) The plan and approach for training personnel (Contractor staff, external maintainers, Flight Operations Team) in the use of all delivered software and supporting facilities.

j) A description of the establishment and maintenance of Software Development Files (SDFs) for CSUs, CSCs, and CSCIs.

k) A Software Maintenance plan that complies with NASA-DID-M300 detailing the plans for software sustaining engineering and long-term maintenance including the role of key members of the Contractor's software development team who will provide continued test and maintenance coverage of the software following its delivery to the

HRV I&T team, the Flight Operations Team, and any external V&V or maintenance organization.

l) A Software Assurance plan that complies with NASA-DID-M400 including the entire software assurance program. The requirements for the assurance program are found in the MAR section 5. The Plan shall include the following:

The Management structure and responsibilities of the organization(s) developing and assuring the software, and its/their relationship to the hardware and flight systems development activities.

A description of the different management and assurance practices to be used for each software criticality and type (reference SOW sections 7.1.3 and 7.1.4).

m) A Risk Management plan that complies with NASA-DID-M500 describing the processes and methods by which technical, cost, and schedule risks will be identified, evaluated, and minimized.

n) A Configuration Management plan that complies with NASA-DID-M600, covering all life cycle phases of the software from requirements through launch or transition to another organization, and including:

Identification of the Computer Software Configuration Items (CSCIs) that will be baselined and maintained under configuration control

Identification of the version control and media labeling methods and procedures

Identification of the requirements management tool and the source code version control tool

A discussion of the timeframe during which the Software CCB (SWCCB) may disposition software without the specific knowledge and approval of the system level CCB, and the time after which all proposed software changes shall be boarded by the system level CCB (reference MAR section 5.4).

o) An identification of the constraints to which the development process is subject (for example, use of assembly language, resource limitations, external dependencies, etc.)

Flight Software Element:

p) The plans for acquiring software and/or firmware that will be an integral part of an HRV subsystem(s).

4.5.2 SW-02 Software Delivery and Operations Transition Plan

Description: This document will be used to prepare for, ensure, and monitor the process by which contractual software and accompanying documentation, facilities, and support shall be delivered to the government.

Content: The Software Delivery and Operations Transition Plan shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-M700. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SMP approach or IEEE standards.

In addition to the content required by NASA-DID-M700, include the following topics as well:

a) The approach for delivery each of the Software Elements, including the government's addition of application programs to the core EM FSW delivered by the contractor.

b) The plans for the transition of all deliverable software and supporting databases from its development to its operational phase. The plan shall include delivery and transition of software to its operational state on deliverable simulators or test beds such as the Software Development & Validation Facility (SDVF), FSW Development & Validation Facility (FDVF), and HRV Training Simulator.

c) The plan for maintenance of the DM FSW through HST's end of mission

4.5.3 SW-03 Software Development Activities Plan (SDAP)

Description: This document describes the Contractor's processes and activities used in the development and testing of each Software Element (Flight software, Software Development & Validation software).

Content: The Software Development Activities Plan shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-M200. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SMP approach such as MIL-STD-498 or IEEE standards.

In addition to the content required by NASA-DID-M200, include the following topics as well:

a) A description of the software decomposition.

b) The resource planning to the lowest level components of the software decomposition known at the time of document publication.

c) A description of the project software standard detailing programming practices, conventions, and standards to all languages in use for implementation.

d) A build-delivery matrix describing the functionality and delivery schedule for software builds.

e) A sample or description of the requirements and design documentation formats.

Flight Software Element:

f) The plan for the level of embedded software support to be provided for the DM software/hardware integration effort. The Plan shall address integration support concepts such as the capabilities of the embedded software under test during periods of variable hardware and software configuration, capabilities of the software to determine the cause of anomalies (hardware verses software), and the capabilities of built-in tests.

g) The method of tracking and correcting any software defects identified during DM I&T and the organization responsible for correcting the defects. The plan shall address the procedures for re-installing non-volatile memory as part of the corrective process.

h) A description of the hardware/software interface testing to take place on DM.

Software Development and Validation (SDV) Software Element:

i) The Plan shall detail the method of tracking and correcting any software defects identified during DM I&T and the organization responsible for correcting the defects.

4.5.4 SW-04 Software Requirements Specification (SRS)

Description: The Software Requirements Specification specifies in detail each Software Element's requirements for a particular Computer Software Configuration Item (CSCI), including functional and performance requirements, interface requirements, testing requirements, security and safety requirements.

Content: The Software Requirements Specification shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-P200. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SRS approach such as MIL-STD-498 (DID DI-IPSC-81433A) or IEEE standards.

In addition to the content required by NASA-DID-P200, include the following as well:

A traceability matrix that maps each software requirement to a system or sub-system (higher level) requirement from which it is derived. Additionally, the test method used to verify each requirement shall be identified.

Software Interface Requirements, as specified in P200, Section 4.0, may optionally become a rolled-out volume. The information shall cover both the software-to-software and software-to-hardware interfaces.

4.5.5 SW-05 Algorithms Design Document(s) (ADD)

Description: An Algorithm Design Document (ADD) shall fully describe a DM Subsystem, defined by Subsystem analysts (e.g., GN&C, Communications, Propulsion), containing algorithms that are utilized and coded into the Flight Software. This document provides intermediary information that the Flight Software developers use to define derived requirements and the design of the flight code.

Content: The Algorithms Design Document shall describe algorithms in sufficient detail to ensure accurate coding. It shall include any mode or state transition diagrams and data/transaction information for each algorithm.

The ADD(s) shall be prepared by the Subsystem experts and delivered to the contractor's DM Flight Software manager.

4.5.6 SW-06 Software Design Document (SDD)

Description: The Software Design Document describes in detail the architecture, structure, and organization of a particular Computer Software Configuration Item (CSCI), decomposing the top-level CSCI into Computer Software Components (CSC) and lower levels of units as appropriate. The SDD describes each unit of software in terms of its interfaces (input/output), data architectures, and processing (eg, logic, algorithms).

Content: The Software Design Document shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-P300/400/410. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SDD approach such as MIL-STD-498 (DID DI-IPSC-81435A) or IEEE standards.

In addition to the content required by NASA-DID-P300/400/410, include the following as well:

A description of utility libraries and routines.

Software Interface Control, as specified in P300/400, section 5.0, may optionally become a rolled-out volume. The information shall cover both the software-to-software and software-to-hardware interfaces.

The Firmware Support Manual (FSM), as specified in NASA-DID-P410, may optionally become a rolled-out volume, and shall contain the information necessary for the firmware programmer to program, support, monitor, troubleshoot, and verify the contents and configuration of the firmware on the spacecraft or in the high-fidelity simulator facilities (SDVF, FDVF, HRV Training Simulator).

4.5.7 SW-07 Software Test Plan (STP)

Description: The Software Test Plan describes the total strategy, methodology, and approach for the complete testing of a particular Computer Software Configuration Item (CSCI) and each of the Computer Software Components (CSCs) and units thereof, including COTS. The STP details the formal acceptance testing strategy of the fully integrated CSCI. The STP shall identify and describe the test environment for each Software Element, for each phase of testing. Any software requirements that require the HRV DM and/or EM spacecraft for testing shall be identified. An Appendix to the STP shall contain the individual test plans for each test procedure or groups of test procedures.

Content: NASA 2100-91 does not have a DID for a Software Test Plan, therefore the contractor shall prepare the STP IAW Table of Contents below, or the full contents of an alternative industry standard STP approach such as MIL-STD-498 (DID DI-IPSC-81438A) or IEEE standards.

- 1.0 Introduction
- 2.0 Test Environment
    - 2.1 Facility Description
    - 2.2 Certification
- 3.0 Test Team
    - 3.1 Test Team Identification
    - 3.2 Test Team Skills Requirements
    - 3.3 Test Team Member Responsibilities
- 4.0 Approach

In addition to the content required by the TOC or DID DI-IPSC-81438A, include the following as well:

a) The Draft STP shall contain a traceability matrix that maps all requirements in the SRS to their corresponding test cases, analyses, inspections, etc. The Final STP traceability matrix shall include the additional mapping of test cases to test procedures/scripts.

b) A description of the scope of testing for the different classifications and types of software, as specified in the SOW section 7.

c) The plan for any hardware/software integration tests to demonstrate software requirements.

d) The plan for test support facilities, equipment, and tools needed for the testing.

e) The plan for any required support from other organizations.

As an Appendix to the STP, individual Test Plans for each test shall be developed specifying at least the following:

f) A description of the individual test and the requirement(s) it will validate.

g) The environment under which the test is to be conducted.

h) The data required for the test, the expected results, and any constraints.

4.5.8 SW-08 Software Test Procedures & Results (STPr)

Description: The Software Test Procedures contain the step-by-step procedures for implementing each software test in the Software Test Plan. This includes the detailed procedures for data reduction and the analysis of test results. Computer-based automated test procedures/scripts implemented by the Contractor to automate the software testing shall be included in the document or as an appendix. The actual input and output files and plots created during the testing or during post-test analysis shall be included in this deliverable. See Preparation Information for the format of these test result products and the timeframe for their delivery.

Content: The Software Test Procedures and Results shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-A000/A100/A200. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard STPr approach such as MIL-STD-498 (DID DI-IPSC-81439A) or IEEE standards.

In addition to the content required by NASA-DID-A000/A100/A200, include the following as well:

a) A traceability matrix that maps all test procedures to their corresponding SRS requirement(s).

b) The delivery format of the automated test scripts and test results, including test history logs and plots, shall be electronic, and hosted on a server with HRV Project access. Delivery shall be in place until the Contractor's responsibility for the software is concluded.

If a hardcopy of test results are required by the government prior to the transition to software maintenance by the HST Program, the HRV Project shall arrange for the test results to be copied by the government, a third party, or the Contractor.

c) At the time of transition to software maintenance by the HST Program, the automated test scripts and test results, including test history logs and plots, shall be delivered in electronic format.

4.5.9 SW-09 Software Test Reports (STR)

Description: The Software Test Report summarizes the results of all formal testing of a particular Computer Software Configuration Item (CSCI).

Content: The Software Test Report shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-R009. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard STR approach such as MIL-STD-498 (DID DI-IPSC-81439A) or IEEE standards.

In addition to the content required by NASA-DID-R009, include the following as well:

a) Version identification of the product(s) under test
b) Version identification of the Development/Lab Environment
c) Planned tests verses successfully completed tests
d) Conformance of the test results to the expected results
e) The number, type, and criticality of the discrepancies found
f) Any future re-testing that is planned, and the timeframe of this testing

4.5.10 SW-10 Version Description Document (VDD)

Description: The Version Description Document (VDD) describes in detail the contents of a particular specified version of the Element Software CSCI. The VDD includes the procedures for generating, building, compiling, and linking it, as well as the files it contains, and the changes from the previous version. This shall also include any tested and verified Change Requests or Problem Reports contained in this version of the software.

Content: The VDD shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-P500. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SDD approach such as MIL-STD-498 (DID DI-IPSC-81442A) or IEEE standards.

4.5.11 SW-11 Software User and Maintenance Manual (SUMM)

Description: The Software User and Maintenance Manual (SUMM) for each Software Element shall contain the information required to use and maintain the software, including detailed procedures for building and troubleshooting. For the Flight Software Element, information on linking and "patching" (i.e., fixing / modifying / replacing portions of) the flight software shall also be included.

Content: The SUMM shall be prepared IAW the full contents of NASA-Software Documentation Standard (NASA STD-2100-91), Data Item Description NASA-DID-P600/700. Alternatively, the contractor may, with agreement from the government, use an alternative industry standard SDD approach such as MIL-STD-498 (DID DI-IPSC-81443A) or IEEE standards.

In addition to the content required by NASA-DID-P600/700, include the following as well:

a) Human interfaces to software systems
b) On-orbit operating constraints for the Flight Software

4.5.12 SW-13 Software Development and Validation Facility User's Manual

Description: The Software Development & Validation Facility (SDVF) User's Manual shall enable those persons testing Flight Software to successfully operate the SDVF, FDVF, HRV Training Simulator under nominal and anomalous circumstances.

Content: The User's Manual shall contain descriptions of the Facility hardware and software, and through the use of procedures and examples, explain the steps from powering on the equipment, through successful testing, and powering down. Error recovery procedures shall also be included. The format of this document is left to the Contractor to define, subject to review and approval by the HST Program.

4.5.13 SW-14 Software Development Files (SDFs)

Description: The Software Development Files (Folders) for the Flight Software transitioning to HST Program maintenance shall include requirements, design, and test documentation for a CSU or CSC, plus technical memos, notes, and results of peer walkthroughs with action item responses.

Content: The Software Development Files shall be prepared and delivered in a format mutually agreeable with the Contractor and the HST Program.

4.5.14 SW-15 Software Review Packages

Description: The contractor shall hold reviews for each Software Element. They may be scheduled adjacent mission (or other) reviews but are held separately. These reviews shall provide a greater understanding and in-depth look at the software, and the processes in use to design, implement, test and verify.

Content: Review packages for software reviews:

a) Flight Software Requirements Review
   - See 580-CK-005-01, Contents of the Software Requirements Review checklist for minimum required contents of the Review and review package
b) Flight Software Preliminary Design Review
   - See 580-CK-007-01, Contents of the Software Preliminary Design Review checklist for minimum required contents of the Review and review package
c) Flight Software Critical Design Review
   - See TBD Checklist for the minimum contents of the Software Critical Design Review and review package
d) Flight Software Test Readiness Review
   - See TBD Checklist for the minimum contents of the Software Test Readiness Review and review package
e) Flight Software Acceptance Review
   - See TBD Checklist for the minimum contents of the Software Acceptance Review and review package

4.5.15 SW-16 Software Measures (Metrics) Report

Description: The Software Measures Report shall highlight the required measures for the period, and summarize all software problems and corrective actions. It will provide information that will be used by the government for trending and risk mitigation.

Content:

I. Software Management inputs:

g. Software Measures (Metrics) including
   i. Number of requirements established, modified, deleted, or derived
   ii. Source code production rates estimates verses actuals
   iii. Number of Software Change Requests/Problem Reports and their status
   iv. Number of requirements validated or number of test cases successfully completed compared to the total
   v. Flight processor resource utilization estimates and measurements for memory, CPU, bus bandwidth, and I/O bandwidth

2. Effort data (man-hours or man-months)
3. Organization and key personnel changes
4. Significant problems or issues that could affect cost, schedule and/or performance
5. Recommendations for corrective action

6. Significant accomplishments and progress
7. Changes to the software build and delivery schedule
8. The status of Risk issues and mitigation efforts
9. The status of any unresolved Review Item Discrepancies (RIDs) from Software Reviews

II. Software Assurance inputs:
1. Assurance accomplishments and resulting software assurance metrics for activities such as, but not limited to, inspection and test, reviews, Contractor/subcontractor surveys, and audits
2. Subcontractor assurance accomplishments, including items listed above
3. Trends in software quality metric data (e.g. total number of software problem reports, including the number of problem reports opened and closed in that reporting period
4. Plans for upcoming software assurance activities

III. Lessons Learned for Software

4.5.16 SW-17 Training Materials

Description: Users of the Flight Software and users of the delivered test bed facilities require training. Materials shall enable the HST Program to successfully operate the HRV software.

Content: Contractor personnel closely involved with the development and V&V of the Flight Software, and involved in the development and certification of the FSW Development & Validation Facility (FDVF) and HRV Training Simulator shall develop and present training materials to the following groups:

Project Development/V&V Team
Flight Operations Team
HST Program personnel

Training materials shall include, but not be limited to, presentation charts, graphical or video presentations, oral presentations, and hands-on demonstrations on the facilities.

The Flight Software topics covered by the training materials shall include, but not be limited to, nominal execution, responses to anomalies, differences between the test environment and the actual performance of the HRV Flight Software, and constraints and software safety related information. Additional topics shall be included at the discretion of the HST Program.

The FDVF and Training Simulator training shall include all information and tutorials required such that the users of the facilities do not need routine support from the Contractor in order to successfully and safely execute their tests and simulations. In addition to training on the test procedure language and test script generation, topics shall include, but not be limited to, power up and power down, constraints, safety features, tools such as in-circuit emulators, bus monitors and logic analyzers, and offline analysis and display tools.

4.5.17 SW-18 Subsystem High-Level Software Simulator(s)

Description: Delivering the high-level subsystem analysis modeling environments allows the HRV Project to independently assess the validity of the models. The Flight Software maintainers will use the models to develop changes to the flight software and to generate algorithm performance data for comparison to flight software output.

Content: For any subsystem actively controlled by Flight Software for which there is a modeling or analysis program used by the subsystem engineers to develop and validate the requirements and design for the Flight Software (reference SW-05), the Contractor shall deliver the program(s) in a working environment. If a COTS product is part of the application, it shall be the responsibility of the Contractor to procure a version of the COTS product that will work for the application.

Only the final version of the modeling/analysis programs shall be delivered with the exception of the programs required under the GN&C section (Attitude Determination and Control, Absolute Orbit Determination, Propulsion System, and Relative Navigation and Control). The contractor shall deliver a preliminary design version, a critical design version, and a pre-launch version of the GN&C programs.

The product deliverable shall include, but not be limited to:

a) Source Code and Data
b) Listing files
c) Object Code and Data
d) Executable Code and Data
e) Build procedures
f) System libraries
g) User instructions
h) Examples of previous program runs and outputs

4.5.18 SW-19 Flight Software Releases

Description: This is the software and firmware that will be flown in the embedded microprocessor(s) of the DM (and EM if chosen and approved by the government per SOW 7.1.1).

Content: This software shall be designed, developed, fully tested, and have completed all assurance verification and validation processes as required in the SOW, Specification, and MAR for the Flight Software Element.

The Flight Software product deliverable for each baseline build shall include, but not be limited to:

a) Source Code and Data
b) Listing files
c) Object Code and Data
d) Executable Code and Data
e) Build procedures
f) System libraries
g) Link map

Four copies shall be delivered, one for each of the following facilities:

1. The DM Contractor's SDVF
2. The HST Program's FDVF
3. The HST Program's Training Simulator
4. The HST Program Library

The delivery format shall be electronically transferable files.

Firmware deliveries shall also include the PROMs that are installed by the Contractor into the HRV flight components and the simulator facilities mentioned above.

4.5.19 SW-21 Software Development and Validation (SDV) Software Releases

Description: This is the baseline software and firmware that will host the flight software development tools, and the simulation environment that will validate the requirements of the flight software.

Content: This software shall be designed, developed, fully tested, and have completed all assurance verification and validation processes as required in the SOW, Specification, and MAR for the SDV software Element.

The SDV Software product deliverable for each baseline build shall include, but not be limited to:

a) High level language cross-compiler and tools for target flight computer
b) Target computer opcode emulator
c) Assembler for low level flight code
d) Software support environment software
e) Software analysis tools
f) Graphic display tools
g) Documentation and CM tools
h) System libraries
i) Attitude dynamic environment models
j) Spacecraft sensor and actuator models
k) Spacecraft subsystem and robotic models

Four (4) copies shall be delivered, one for each of the following facilities:

1. The HRV Contractor's SDVF
2. The HST Program's FDVF
3. The HST Program's Training Simulator
4. The HST Program Library

The delivery format shall be electronically transferable files.

Firmware deliveries shall also include the PROMs that are installed by the Contractor into the HRV flight components and the simulator facilities mentioned above.

4.5.20 SW-23 SDVF/FDVF/Training Simulator Specification

Description: This document is used to specify the hardware and special purpose software requirements imposed on the simulators that are not encompassed in DRD SW-21, Software Development and Validation (SDV) Software Releases. It establishes the framework for facility certification.

Content: This document defines the hardware functional, performance, and verification requirements for the simulators. The document shall define the applicable inter-system interfaces by medium and by function, including data content, format, direction, digital level definitions, voltage and current limits, timing and/or sequencing constraints, and all specified accuracies and resolution requirements.

The format of this document is left to the Contractor to define, subject to review by the HRV Project.

4.5.21 SW-24 SDVF/FDVF/Training Simulator Drawings, Wiring, and Parts List

Description: This document includes all the supporting hardware documentation to maintain the special purpose hardware in the deliverable facilities (Software Development & Validation Facility, and its two copies, the FSW Development & Validation Facility and the HRV Training Simulator).

Content: This document shall include the hardware drawings and specifications, parts lists, and wiring diagrams created for the development and certification of the deliverable facilities. The document shall be delivered with the facilities for long-term maintenance purposes.

The format of these documents is left to the Contractor to define, subject to review by the HST Program.

4.6 TESTING

These deliverables are prepared by the DM Contractor for use at the next higher level of assembly, the HST Robotic Vehicle (HRV).

4.6.1 Reserved

4.6.2 IT-02 De-orbit Module and GSE Transportation Plan

Description: The DM Transportation Plan defines the preparations, operations support and scheduling required to safely transport the DM (integrated into the HRV) from the GSFC Integration and Testing facility to the launch facility. Included are both ground and air transportation as required.

Content: The content shall include:

a) List of preparations and descriptions with process flow for all activities necessary to pack, receive and unpack the DM.

b) Details of DM transportation requirements, applicable procedures, contamination controls, safety provisions, facilities required, and modes of transportation.

These deliverables pertain to the De-orbit Module element that is the main hardware deliverable for the De-orbit Module contract.

4.7 DE-ORBIT MODULE

4.7.1 DM-01 De-orbit Module Specification

Description: This document provides NASA with a detailed description of the contractor's specifications for a De-orbit Module that meets the De-orbit Module Requirements as specified in the **Requirements Document**.

Content: This is a Contract End-Item Specification. This document shall cover system requirements and subsystem requirements for the DM. This document shall include traceability to the **Requirements Document**.

4.7.2 DM-02 De-orbit Module Verification Plan

Description: This document provides NASA with a detailed description of the Contractor's approach to the verification of the requirements in the **Requirements Document**.

Content: The plan shall describe the overall approach for requirements verification of the DM. The plan shall define the tasks and methods required to verify that the DM meets each performance requirement in the **Requirements Document**. The plan shall define the tasks and methods required to verify that the DM will operate successfully in the environments it will encounter throughout its lifetime. The plan shall include an environmental test matrix as described in GEVS-SE.

4.7.3 DM-03 De-orbit Module Integration and Test Plan

Description: The Test Plan provides a detailed description of how the Contractor shall execute, in a cost-effective manner, the overall testing activity to validate that the DM conforms to the requisite performance specifications including environmental exposures (radiation, thermal vacuum, thermal balance, vibro-acoustic, shock, etc.).

Content: The content shall include:

- Test objectives
- Roles and responsibilities of the members of the test team
- Test requirements, including requirements definition and management, data reduction/analysis and management, reporting of discrepancies, and rework and retest provisions
- Security, safety, and precautionary provisions to safeguard the DM and personnel

- Facility cleanliness and contamination control provisions
- DM testing flow/description, with facilities, GSE, configurations, and list of procedures
- Test equipment requirements, and facilities including descriptions with capabilities
- Test program description, including test sequence, objectives of each test, preparations required, facilities, GSE, configurations, and list of procedures
- Facility planning and modification plans

4.7.4 DM-04 De-orbit Module Test and Verification Reports

Description: These reports summarize compliance with system specification requirements and/or provide a summary of testing and analysis results, including conformance, nonconformance, and trend data.

Content: The content shall include:

- Validation Report: Provide after DM validation activity. For each analysis activity the validation report shall describe the degree to which the objectives were accomplished, how well the mathematical model was validated by the test data, and other significant results.
- System Performance Validation Report: Compare hardware/software specifications with the verified values (whether measured or computed).

4.7.5 DM-08 De-orbit Module Thermal-Mechanical Simulator User's Manual

Description: The De-orbit Module Thermal-Mechanical Simulator User's Manual provides details regarding the use of the simulator.

Content: This user's manual shall include details for how the De-orbit Module Thermal-Mechanical simulator is operated. It shall detail each operational mode and test scenario used for HRV testing.

4.7.6 DM-09 De-orbit Module Thermal-Mechanical Simulator Design Document

Description: The De-orbit Module Thermal-Mechanical Simulator Design Document provides design details for the simulator.

Content: The De-orbit Module Thermal-Mechanical Simulator Design Document shall include details for how the simulator is designed and how it supports HRV testing. Details shall include design diagrams and data flow.

4.7.7 DM-15 De-orbit Module Electrical Simulator User's Manual

Description: The De-orbit Module Electrical Simulator User's Manual provides details regarding the use of the simulator.

Content: This user's manual shall include details for how the De-orbit Module Electrical simulator is operated. It shall detail each operational mode and test scenario used for HRV testing and HST operations support.

4.7.8 DM-16 De-orbit Module Electrical Simulator Design Document

Description: The De-orbit Module Electrical Simulator Design Document provides design details for the simulator.

Content: The De-orbit Module Electrical Simulator Design Document shall include details for how the simulator is designed and how it supports HRV testing and HST operations support. Details shall include design diagrams and data flow.

4.8 OPERATIONS

These deliverables pertain to operational and training aspects of the De-orbit Module.

4.8.1 OPS-01 Project Data Base (PDB) Certification Plan

Description: The PDB Certification Plan defines the plan and process for certifying all contents of the PDB that are developed to operate the DM Ground Segment.

Content: The PDB Certification Plan shall contain the details regarding the methods and processes that will be employed to approve and certify all PDB contents.

The PDB certification plan shall include the following:
1.0 Introduction
2.0 PDB Overview
3.0 DM levels of verification for certification
    3.1 Level 1 - PDB population
    3.2 Level 2 – Initial verification and sign-off
    3.3 Level 3 – Functional verification and sign-off
4.0 Certification tracking and management
5.0 Certification guidelines (responsibilities matrix)

4.8.2 OPS-02 Project Data Base (PDB) Certification Reports

Description: The PDB Certification Reports are the actual sign-off/certification documents that list the PDB parameters and contain the appropriate level signature.

Content: The PDB Certification Reports shall contain the itemized listing for all parameters by file, and contain the level of certification performed, signature and date.

4.8.3 OPS-03 Reference Data Description Document

Description: The Reference Data Description Document (RDDD) describes the commands, procedures, calibration, algorithms and reference data necessary to control and configure the DM or trend DM performance. Individual command definition shall include the data type, data length, parameter length and definition, illegal state constraints, scaling and special action identification, and verification methods.

Content: The DM RDDD shall follow the requirements and interfaces defined in the Flight to Ground IRD and ICD. The document shall contain the data range and calibration tables for each command. It shall provide a format description, mnemonic, type, function, bit configuration, subsystem, and criticality indicator for each command.

The DM RDDD shall include the following:

1.0 Introduction
- 1.1 Purpose and Scope
- 1.2 Mission Overview
- 1.3 Document Overview
- 1.4 Context/Assumptions
- 1.5 Applicable Documents
  - 1.5.1 Government Documents
  - 1.5.2 Non-Government Documents
- 1.6 Updates and Revisions

2.0 Command Sequences
- Appendices
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.4 OPS-04 Operations Handbook

Description: This document provides a detailed description of the DM interfaces and operations. It also provides instructions on the use during acceptance testing. The Operations Handbook describes the flow of commands and data between the ground and flight segments. The scenarios encompass normal and contingency operations. The documented scenarios are consistent with operational restrictions and constraints defined in the CARD and the OLD.

Content: The document shall contain sections for each mechanical, optical, and electrical interface provided by the Contractor for use during acceptance testing and mission execution.

The Operations Handbook shall include the following:

- Preface
- Abstract
- Change Information
- Table of Contents

1.0 Introduction
- 1.1 Purpose and Scope
- 1.2 Mission Overview
- 1.3 Document Overview
- 1.4 Context/Assumptions
- 1.5 Applicable Documents
  - 1.5.1 Government Documents
  - 1.5.2 Non-Government Documents
- 1.6 Updates and Revisions

2.0 Operations Overview
- 2.1 Introduction
- 2.2 DM Goals and Science
- 2.3 Ground System
  - 2.3.1 Overview

2.3.2 Interfaces
2.3.3 Ground System Language
2.3.4 Remote Users
2.3.5 Simulators
2.3.6 I&T Facilities
3.0 Command
3.1 Command Overview
3.2 Command Data Path
3.3 Command Failure/Troubleshooting Flows
4.0 Telemetry
4.1 Telemetry Overview
4.2 Telemetry Data Path
4.3 Telemetry Failure/Troubleshooting Flows
5.0 Operations Policies
5.1 DM Recovery Policies
5.2 Configuration Management of Policies and Procedures
5.3 Configuration Management of Ground System Upgrades
5.4 Information Distribution
6.0 Operations Procedures
6.1 Routine Operations Procedures
6.2 Contingency Operations Procedures
6.3 Fault Isolation Procedures
6.4 Safemode Recovery Procedures
6.4.1 Recovery of Spacecraft
6.4.2 Intercepting DM Schedule
- Appendices:
- Appendix A - Policies
- Appendix B - Procedures
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.5 OPS-05 De-orbit Module Constraints and Restrictions Document (CARD)

Description: The DM Constraints and Restrictions Document (CARD) provides the results of Contractor analyses of the DM flight segment, and identifies prohibited configurations and operations which will or might result in hardware damage.

Content:

The purpose of the CARD is to establish the methods employed by the Contractor and the ground system to manage operational constraints and restrictions. The document shall provide implementation traceability from the CARD to the content of the ground system software and its supporting project database files.

Information shall be provided to describe how the constraints and restrictions are managed through ground system procedures, operational procedures and/or ground/flight software.

The DM Constraints and Restrictions Document (CARD) shall include the following:

- Preface
- Abstract
    - Change Information
    - Table of Contents

1.0 Introduction
    1.1 Purpose and Scope
    1.2 Mission Overview
    1.3 Document Overview
    1.4 Context/Assumptions
    1.5 Applicable Documents
        1.5.1 Government Documents
        1.5.2 Non-Government Documents
    1.6 Updates and Revisions
2.0 DM System Overview
3.0 Mission Operations Overview
4.0 DM Constraints
    4.1 Structures and Mechanical Subsystems
    4.2 Instrumentation and Communication System
    4.3 Data Management Subsystem
    4.4 Pointing and Control Subsystem
    4.5 Electrical Power Subsystem
    4.6 Thermal Control Subsystem
    4.7 Safing System
    4.8 Flight Software
5.0 DM Restrictions
    5.1 Structures and Mechanical Subsystems
    5.2 Instrumentation and Communication System
    5.3 Data Management Subsystem
    5.4 Pointing and Control Subsystem
    5.5 Electrical Power Subsystem
    5.6 Thermal Control Subsystem
    5.7 Safing System
    5.8 Flight Software

- Appendices
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.6 OPS-06 De-orbit Module Operations Limitations Document (OLD)

Description: The DM Operations Limitations Document (OLD) provides the results of contractor analyses of the DM flight segment, and identifies configurations and operations that could result in a loss of observing time or data.

Content:

This document shall provide DM mission operations limitations. An operations limitation is identified as a practice or procedure that if violated will cause temporary loss of data, temporary degradation of components within the Observatory, cause subsystem inconvenience or loss of operating time but will not cause components damage.

The DM Operations Limitations Document (OLD) shall include the following:

- Preface
- Abstract
- Change Information
- Table of Contents

1.0 Introduction
- 1.1 Purpose and Scope
- 1.2 Mission Overview
- 1.3 Document Overview
- 1.4 Context/Assumptions
- 1.5 Applicable Documents
  - 1.5.1 Government Documents
  - 1.5.2 Non-Government Documents
- 1.6 Updates and Revisions

2.0 DM System Overview

3.0 Mission Operations Overview

4.0 DM Operations Limitations
- 4.1 Structures and Mechanical Subsystems
- 4.2 Instrumentation and Communication System
- 4.3 Data Management Subsystem
- 4.4 Pointing and Control Subsystem
- 4.5 Electrical Power Subsystem
- 4.6 Thermal Control Subsystem
- 4.7 Safing System
- 4.8 Flight Software

5.0 DM Nominal Operating Temperature Limitations
- 5.1 Structures and Mechanical Subsystems
- 5.2 Instrumentation and Communication System
- 5.3 Data Management Subsystem
- 5.4 Pointing and Control Subsystem
- 5.5 Electrical Power Subsystem
- 5.6 Thermal Control Subsystem
- 5.7 Safing System

- Appendices
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.7 OPS-07 Flight System Description and Operations Manual

Description: The DM Flight System Description and Operations Manual describes the spacecraft subsystems and their functions (including operational modes, and operating guidelines). The DM flight operations team uses it during training and operations.

Content:

The DM Flight System Description and Operations Manual shall contain detailed descriptions of each component of the DM. Along with these descriptions shall be the nominal and contingency operations scenarios of the components, photos, schematics, flow diagrams and communications interfaces both internal and external to DM.

The DM Observatory Flight System Description and Operations Manual shall include the following:

- Preface
- Abstract
- Change Information
- Table of Contents

1.0 Introduction
- 1.1 Purpose and Scope
- 1.2 Mission Overview
- 1.3 Document Overview
- 1.4 Context/Assumptions
- 1.5 Applicable Documents
  - 1.5.1 Government Documents
  - 1.5.2 Non-Government Documents
- 1.6 Updates and Revisions

2.0 DM System Description

3.0 Launch Site Operations
- 3.1 Listing and Description of Major Requirements
  - 3.1.1 Data Acquisition, Processing, Distribution and Storage
  - 3.1.2 Launch Site Facilities
  - 3.1.3 Launch Site Support Services
  - 3.1.4 Training
  - 3.1.5 GSE
- 3.2 Operations Approaches
- 3.3 Major Operations Functions to be Performed
- 3.4 Schedule Planning for Operations Functions
- 3.5 Operations Flows and Timelines
- 3.6 Interfaces with Other Operations Elements

4.0 Mission Operations
- 4.1.2 Post-Separation Configuration
  - 4.1.2.1 Command and Data Handling Subsystem
  - 4.1.2.2 RF Subsystem
  - 4.1.2.3 Electrical Power Subsystem
  - 4.1.2.4 Thermal Subsystem
  - 4.1.2.5 Attitude Determination and Control Subsystem

4.1.2.6 Propulsion Subsystem
4.1.2.7 Flight Software
4.2 Major Operations Functions to be Performed
4.3 Schedule Planning for Operations Functions
4.4 Operations Flows and Timelines
4.5 Interfaces with Other Operations Elements
5.0 Contingency Operations
5.1 Listing and Description of Major Requirements
5.2 Contingency Functions to be Performed
5.3 Identification of Critical Conditions and Constraints
5.4 Description of Corrective Actions for Major Anomalies
5.5 Operations Flows and Timelines
5.6 Interfaces with Other Operations Elements
- Appendices
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.8 OPS-08 Training Scenarios and Training Course Materials

Description: The Training Scenarios and Training Course Materials Document provides the instructional content needed to train and qualify the operations team for flight operations duty.

Content:

The document shall contain descriptions of each constituent of the DM, ground stations, ground network, and ground system. The training material shall be correlated with the DM flight system description and operations manual. The training material shall include flow diagrams for nominal and contingency operations, photos, test materials to demonstrate proficiency, course outlines, and training schedules. As much as possible, this training shall be computer based and integrated with simulator freeze files.

The Training Scenarios and Training Course Materials Document shall include the following:

- Preface
- Abstract
- Change Information
- Table of Contents
1.0 Introduction
1.1 Purpose and Scope
1.2 Mission Overview
1.3 Document Overview
1.4 Context/Assumptions
1.5 Applicable Documents
1.5.1 Government Documents
1.5.2 Non-Government Documents

5.5.2 Updating of Training Material
5.5.3 Updating of Test Material
5.5.4 Proficiency Testing
5.6 Record Keeping
5.6.1 Training Report
5.6.2 Personnel Training Record
5.6.3 Skills Catalog
5.6.4 Proficiency Training Log
5.6.5 Proficiency and Attributes Evaluation
5.6.6 Certification Summary Sheets
5.7 Re-testing
- Appendices:
- Appendix A - Training Session Description
- Appendix B - Certification Summary Sheets
- Abbreviations and Acronyms
- References
- List of Tables
- List of Figures

4.8.9 OPS-09 Flight Procedures Handbook

Content: This is section 6 of OPS-04.

APPENDIX: ABBREVIATIONS AND ACRONYMS

ABBREVIATION/ ACRONYM	DEFINITION
CDR	Critical Design Review
CCP	Contamination Control Plan
CM	Configuration Management
COTR	Contracting Officer Technical Representative
DILS	Data Items List and Schedule
DM	De-orbit Module
DRD	Data Requirement Document
ETU	Engineering Test Unit
FDH	Fault Detection and Handling
FEA	Finite Element Analysis
FSW	Flight Software
FS	Flight Spare
FU	Flight Unit
FDVF	FSW Development & Validation Facility
GEVS-SE	General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components
HRV	Hubble Robotic Vehicle
IAW	In accordance with
ICD	Interface Control Document
IRD	Interface Requirement Document
OV	Orbital Verification
PAR	Performance Assurance Requirement
PCM	Program Control Milestone
PDB	Project Data Base
PDR	Preliminary Design Review
PRD	Performance Requirements Document
PSR	Pre-Ship Review
QA	Quality Assurance
SDVF	Software Development & Validation Facility
SOW	Statement of Work
SRR	System Requirements Review
TRR	Test Readiness Review
WBS	Work Breakdown Structure

Mission Assurance Requirements SMR-5000

for the

Hubble Space Telescope (HST) HST Robotic Vehicle (HRV) De-orbit Module (DM)/ Disposal Vehicle (HDV)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

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1.0 OVERALL REQUIREMENTS

This chapter addresses the overall Mission Assurance Requirements (MAR).

1.1 DESCRIPTION OF OVERALL REQUIREMENTS

The Contractor is required to plan and implement an organized System Safety and Mission Assurance program that encompasses (1) all flight hardware, either designed/built by the Contractor or furnished by the Goddard Space Flight Center (GSFC), from project initiation through launch and mission operations, (2) ground support equipment (GSE) that interfaces to flight hardware to the extent necessary to assure the integrity and safety of flight items, and (3) all software critical for mission success. This plan shall be documented in a Mission Assurance Plan (MAP) or contractor equivalent, see Section 1.6 and DID 1-1.

1.2 USE OF MULTI-MISSION OR PREVIOUSLY DESIGNED, FABRICATED, OR FLOWN HARDWARE

Hardware that was designed, fabricated, or flown on a previous project will be considered to have demonstrated compliance with some or all of the requirements of this document such that certain tasks need not be repeated provided that the Contractor can adequately demonstrate how the hardware complies with requirements.

1.3 SURVEILLANCE OF THE CONTRACTOR

The work activities, operations, and documentation performed by the Contractor or suppliers are subject to evaluation, review, audit, and inspection by government-designated representatives from GSFC, the Government Inspection Agency (GIA), or an independent assurance contractor (IAC). GSFC will delegate in-plant responsibilities and authority to those agencies via a letter of delegation, or the GSFC contract with the IAC

The contractor and/or suppliers shall grant access for that National Aeronautics and Space Administration (NASA) and/or NASA representatives to conduct an assessment/survey upon notice. Resources shall be provided to assist with the assessment/survey with minimal disturbance to work activities. The contractor, upon request, shall provide government assurance representatives with documents, records, and equipment required to perform their assurance and safety activities. The contractor shall also provide the government assurance representative(s) with an acceptable work area within contractor facilities.

1.4 END ITEM DATA PACKAGE

Hardware that is fabricated, assembled, and/or tested shall have a data package that contains pedigree documentation sufficient to validate the hardware as space-flight qualified (see DID 1-2).

1.5 APPLICABLE DOCUMENTS

To the extent referenced herein, the documents listed in Chapter 16 form a part of this document.

1.6 ACRONYMS, ABBREVIATIONS AND DEFINITIONS

Chapter 17 defines acronyms and abbreviations and Chapter 18 defines the terms as applied in this document.

1.7 PROPOSED ALTERNATIVES

The overall intent of this document is to ensure that system safety is properly addressed and that developed hardware and systems will successfully meet NASA and the HRVDM/HDV requirements. It is recognized, however, that alternative approaches, to those presented here, may accomplish these same goals with less paperwork or in a more productive manner. Accordingly, the Contractor is encouraged to propose alternative methods that might be more efficient, but still meet the needs defined by this document.

2.0 QUALITY MANAGEMENT SYSTEM

The Contractor shall have a Quality Management System (QMS) that is compliant with the minimum requirements of American National Standards Institute (ANSI)/ISO/American Society for Quality (ASQ) Q9001 or equivalent. The Contractor's Quality Manual shall be provided in accordance with the SOW (refer to DID 2-1). Certificates issued to ANSI/ISO/ASQC Q9001: 1994 will have a maximum validity of 3 years from the publication date of ANSI/ISO/ASQ Q9001: 2000.

2.1 SUPPLEMENTAL QUALITY MANAGEMENT SYSTEM REQUIREMENTS

Some assurance related activities are not covered by ISO requirements. These activities are identified in the following sections and should supplement the ANSI/ISO/ASQ 9001 requirements. The Contractor shall provide a Mission Assurance Plan describing how the requirements in this document will be met. (refer to DID 2-2).

2.2 CONFIGURATION MANAGEMENT

The Contractor shall document and maintain a configuration management system to properly manage change control and the functional and physical characteristics of configuration items during design, fabrication, assembly, and testing. The Contractor's Configuration Management Plan shall be available for review by GSFC.

2.2.1 Control of Nonconforming Product

The Contractor shall have a closed loop system for identifying and reporting nonconformances, ensuring that positive corrective action is implemented to preclude recurrence and verification of the adequacy of implemented corrective action by audit and test as appropriate. The system shall include a nonconformance review process, which shall consist of a preliminary review and a Material Review Board (MRB). The HRVDM/HDV Project shall be provided access to the HRVDM/HDV related nonconforming reports and corrective action information.

2.2.2 Material Review Board (MRB)

At Contractor/supplier facilities, the NASA/Government representatives will participate in MRB activities as deemed appropriate by GSFC.

2.2.3 Reporting of Nonconformances

Reporting of hardware and software nonconformances shall begin with the first power application at the start of end item acceptance testing or the first operation of a mechanical item; it shall continue through formal Government acceptance of the end item.

2.2.4 Control of Monitoring and Measuring Devices

Testing and calibration laboratories shall be compliant with the requirements of ISO 17025, "General Requirements for the Competence of Testing and Calibration Laboratories".

2.2.5 Flow-Down

The Contractor's QA and safety programs shall ensure proper flow-down and verification of requirements to all suppliers.

3.0 SYSTEM SAFETY

This chapter addresses the System Safety Requirements for the HRVDM/HDV Project

3.1 SYSTEM SAFETY REQUIREMENTS

The Contractor shall implement a system safety program in accordance with NPG 8715.3 "NASA Safety Manual" and the requirements of this Chapter. The program is expected to provide for early identification and control of hazards during design, fabrication, test, transportation, and ground activities. Operations/hardware that do not comply with OSHA/NASA safety requirements may cause operation to be discontinued until approved by the appropriate authority. Personnel safety will take precedence over schedule.

The following are mandatory compliance requirements for hardware and software:

a. EWR 127-1, "Eastern and Western Range Safety Requirements".
b. KHB 1710.2, "Kennedy Space Center Safety Practices Handbook
c. NPG 8715.3, "NASA Safety Manual".

Any testing performed at GSFC shall comply with the safety requirements contained in:

a. GMI 1700.2, "Goddard Space Flight Center Health and Safety Program".
b. GSFC document 5405-PG-8715.1.1, "Mechanical Systems Division Safety Manual – Volume I"
c. GSFC document 5405-PG-8715.1.2, "Mechanical Systems Division Safety Manual – Volume II"

Satisfactory compliance with the above requirements is required to gain payload access to the launch site and the subsequent launch.

The Contractor shall participate in Project activities associated with compliance to NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation.

3.2 SYSTEM SAFETY DELIVERABLES

The safety deliverables described in the following sections serve to demonstrate launch range safety requirements.

3.2.1 System Safety Program Plan

The Contractor shall prepare a System Safety Program Plan (SSPP) (see DID 3-1), that describes in detail, tasks and activities of system safety management and system safety engineering required to identify, evaluate, and eliminate and control hazards, or reduce the associated risk to a level acceptable throughout the system life cycle.

3.2.2 Safety Analyses

The Contractor shall conduct or assist GSFC with the following safety analyses.

3.2.2.1 Preliminary Hazard Analysis

The contractor shall perform and document a Preliminary Hazard Analysis (PHA) to identify safety critical areas, to provide an initial assessment of hazards, and to identify requisite hazard controls and follow-on actions.

3.2.2.2 Subsystem Hazard Analysis

The Contractor shall perform and document a Subsystem Hazard Analysis (SSHA) to verify subsystem compliance with safety requirements contained in subsystem specifications and other applicable documents; identify previously unidentified hazards associated with the design of subsystems including component failure modes, critical human error inputs, and hazards resulting from functional relationships between components and equipment comprising each subsystem; and recommend actions necessary to eliminate identified hazards or control their associated risk to acceptable levels.

3.2.2.3 System Hazard Analysis

The Contractor shall perform and document a System Hazard Analysis (SHA) to verify system compliance with safety requirements contained in system specifications and other applicable documents; identify previously unidentified hazards associated with the subsystem interfaces and system functional faults; assess the risk associated with the total system design, including software, and specifically of the subsystem interfaces; and recommend actions necessary to eliminate identified hazards and/or control their associated risk to acceptable levels.

3.2.2.4 Operating and Support Hazard Analysis

The Contractor shall perform and document Operating and Support Hazard Analysis (O&SHA) to evaluate activities for hazards or risks introduced into the system by operational and support procedures and to evaluate adequacy of operational and support procedures used to eliminate, control, or abate identified hazards or risks.

3.2.2.5 Software Safety

Hazards caused by software will be identified as a part of the nominal hazard analysis process, and their controls will be verified prior to acceptance.

3.3 SAFETY ASSESSMENT REPORT

The Contractor shall perform and document a comprehensive evaluation of the mishap risk of their system. This safety assessment (refer to DID 3-2) shall identify all safety features of the hardware, software, and system design, as well as procedural related hazards present in the system.

3.4 MISSILE SYSTEM PRELAUNCH SAFETY PACKAGE

The Contractor shall prepare and submit a Missile System Prelaunch Safety Package (MSPSP) (see DID 3-3) in accordance with EWR 127-1; scope shall include hazards associated with the flight system, ground support equipment, and their interfaces that affect personnel, launch vehicle hardware, or the spacecraft. In addition to identifying hazards, the MSPSP shall also establish a "closed loop" process for tracking all hazards to acceptable hazard control closure through the use of a Verification Tracking Log (VTL), (see DID 3-4). A list of all hazardous/toxic materials and associated material safety data sheets shall be prepared and included in the final MSPSP, as well as a detailed description of the hazardous and safety critical operations associated with the payload. The Contractor Project Manager shall demonstrate compliance with these requirements and shall certify to GSFC and the launch range, through this MSPSP, that all safety requirements have been met.

3.5 GROUND OPERATIONS PROCEDURES

The Contractor shall submit, in accordance with the contract schedule, all ground operations procedures (see DID 3-5) to be used at GSFC facilities, other integration facilities, or the launch site. All launch site procedures shall comply with the launch site and NASA safety regulations.

3.6 HAZARDOUS OPERATIONS

Hazardous operations at the contractor facility and government facilities shall comply with safety training and personnel certification, and operational requirements in NPR 8715.3 NASA Safety Manual.

For work performed at GSFC facilities, the contractor shall also meet the safety requirements contained in GSFC documents 5405-PG-8715.1.1 and 5405-PG-8715.1.2, "Mechanical Systems Division Safety Manual – Volume I & II".

For work performed at launch facilities, the contractor shall also meet the safety requirements contained in the applicable range safety requirements, i.e. EWR 127-1.

3.7 SAFETY NONCOMPLIANCE/WAIVER REQUESTS

When a specific safety requirement cannot be met, the Contractor shall submit an associated safety noncompliance/waiver request (see DID 3-6).

3.8 SUPPORT FOR SAFETY MEETINGS

The Contractor shall provide technical support to the HRVDM/HDV Project for safety working group meetings, Technical Interface Meetings, and technical reviews, when necessary.

3.9 ORBITAL DEBRIS ASSESSMENT

The Contractor shall supply an Orbital Debris Assessment, (see DID 3-7) or the information required to produce the assessment consistent with NPD 8710.3, Policy for Limiting Orbital Debris Generation and NSS 1740.14.

3.10 SAFETY REQUIREMENTS COMPLIANCE

The Contractor shall demonstrate that the payload is in compliance with all safety requirements (or NCRs/waivers have been submitted and approved by GSFC and the launch site safety representative) and document this in the MSPSP.

3.11 LAUNCH SITE SAFETY SUPPORT

The Contractor shall consider manpower requirements necessary for safety support of hazardous operations at the launch site. Range safety is not responsible for project safety support at the launch ranges.

3.12 MISHAP REPORTING AND INVESTIGATION

Any mishaps, incidents, and hazards, and close calls will be reported on a NASA Form NF1627 or equivalent form. Mishaps at GSFC facilities shall be reported in accordance with GPG 8621.1, "Reporting of Mishaps, Incidents, Hazards, and Close Calls". Additional requirements are contained in GPG 8621.2, Processing Mishap, Incident, Hazard, and Close Call Reports.

4.0 RELIABILITY REQUIREMENTS

This chapter addresses the Reliability Requirements for the HRVDM/HDV Project.

4.1 GENERAL REQUIREMENTS

The Contractor shall plan, document and implement a reliability program that interacts effectively with other project disciplines, including systems engineering, hardware design, software reliability, and mission assurance.

4.2 PROBABILISTIC RISK ASSESSMENT

A PRA Planning Document shall be prepared that defines the approach to performing a PRA. The PRA itself shall be performed in accordance with the Contractor's Risk Management Plan. Together the PRA and the PRA planning document shall provide a comprehensive, systematic and integrated approach to identifying undesirable events, the scenarios leading to those events beginning with the initiating event or events, the frequency or likelihood of those events and the event consequences. The assessment shall be used to assist in identifying pivotal events that may protect against, aggravate or mitigate the resulting consequences.

The results of the PRA shall be reported at all system level critical reviews and made available for GSFC inspection upon request.

4.3 RELIABILITY ANALYSES

Reliability analyses shall be performed concurrently with design so that identified problem areas can be addressed and correction action taken (if required) in a timely manner

4.3.1 Failure Modes and Effects Analysis

A Failure Modes and Effects Analysis (FMEA) shall be performed early in the design phase to identify system design problems. As additional design information becomes available the FMEA shall be refined.

Results of the FMEA shall be used to evaluate the design relative to requirements (e.g., no single instrument failure will prevent removal of power from the instrument). Identified discrepancies shall be evaluated by management and design groups for assessment of the need for corrective action. FMEA results shall be presented at PDR and CDR.

4.3.2 Fault Tree Analysis

Fault tree analyses (FTA) shall be performed that address both mission failures and degraded modes of operation. Beginning with each undesired state (mission failure or degraded mission), the fault tree will be expanded to include all credible combinations of events/faults and environments that could lead to that undesired state. Component hardware/software failures, external hardware/software failures, and human factors shall be considered in the analysis

The results of the FTA shall be presented at system level reviews and made available electronically to GSFC upon request.

4.3.3 Parts Stress Analyses

Each application of electrical, electronic, and electromechanical (EEE) parts, shall be subjected to stress analyses for conformance with the applicable derating guidelines. The analyses with summary sheets and updates shall be maintained at the Contractor's facility for GSFC to review/audit.

4.3.4 Worst Case Analyses

Worst Case Analyses shall be performed on circuits where failures would result in questions to the flightworthiness of the design. This analysis (when performed) shall be made available at the Contractor's facility for GSFC review. The results of any analyses shall be presented at all design reviews starting with PDR.

4.3.5 Reliability Assessments and Predictions

When necessary or when agreed-upon with GSFC, the Contractor shall perform comparative numerical reliability assessments and/or reliability predictions to:

a. Evaluate alternative design concepts, redundancy and cross-strapping approaches, and part substitutions

b. Identify the elements of the design which are the greatest detractors of system reliability

c. Identify those potential mission limiting elements and components that will require special attention in part selection, testing, environmental isolation, and/or special operations

d. Assist in evaluating the ability of the design to achieve the mission life requirement and other reliability goals and requirements as applicable

e. Evaluate the impact of proposed engineering change and waiver requests on reliability

4.4 RELIABILITY ANALYSIS OF TEST DATA

The Contractor shall fully utilize test information during the normal test program to assess flight equipment reliability performance and identify potential or existing problem areas.

4.4.1 Trend Analyses

As part of the routine system assessment, the Contractor shall assess all subsystems and components to determine measurable parameters that relate to performance stability. Selected parameters shall be monitored for trends starting at component acceptance testing and continuing during the system integration and test phases. Trend analysis data shall be reviewed with the operational personnel prior to launch.

4.4.2 Analysis of Test Results

The Contractor shall analyze test information, trend data, and failure investigations to evaluate reliability implications. Identified problem areas shall be documented and directed to the attention of Contractor management for action. The results of the analyses shall be presented at design reviews.

4.5 LIMITED-LIFE ITEMS

Limited-life items shall be identified and managed by means of a Limited-Items list. The Limited-Items list shall be presented at PDR, CDR and the PSR.

Records shall be maintained that allows evaluation of the cumulative stress (time and/or cycles) for limited-life items starting when useful life is initiated and indicating the project activity that will stress the items. The use of an item whose expected life is less than its mission design life must be approved by GSFC by means of a program waiver.

5.0 SOFTWARE ASSURANCE REQUIREMENTS

This chapter addresses the Software Assurance Requirements for the HRVDM/HDV Project

5.1 GENERAL

For the purposes of Section 5, all references to the Contractor shall include the prime software Contractor, as well as any subcontractors and team members tasked in the development process.

5.2 SOFTWARE ASSURANCE

The Contractor shall document (DRD SW-01) and implement a Software Assurance program to address software assurance disciplines and functions for all flight and ground system software. The software assurance program shall apply to software and firmware (including PROMs, EEPROMS, and FPGAs) developed or re-used under this contract, including Government off-the-shelf (GOTS) software, modified off-the-shelf (MOTS) software, and commercial off-the-shelf (COTS) software when included in a NASA system.

5.2.1 Software Safety

The Contractor shall conduct a Software Safety program that is integrated with the overall software assurance and systems safety program and is compliant with the software safety requirements of NASA-STD-8719.13.

5.2.2 Verification and Validation

The Contractor shall implement a Verification and Validation (V&V) program to ensure that software being developed or maintained satisfies functional, performance, and other requirements at each stage of the development process and that each phase of the development process yields the right product. To assist in the verification and validation of software requirements, the Contractor shall develop and maintain under configuration control a Software Requirements Verification Matrix. This matrix shall document the flow-down of each requirement to the test case and test method used to verify compliance and the test results. The matrix shall be made available to NASA upon request.

V&V activities shall be performed during each phase of the development process and shall include the following:

1. Analysis of system and software requirements allocation, verifiability, testability, completeness and consistency (including analysis of test requirements).
2. Interface analysis (requirements and design levels).
3. Design and code analyses.
4. Walkthroughs and/or inspections (i.e., engineering peer reviews).
5. Formal Reviews.
6. Documented test plans and procedures.
7. Test planning, execution, and reporting.

Class I changes are defined as those which affect System requirements or Software requirements; Software Safety; Cost or Schedule; or External Interfaces.

5.5 SOFTWARE PROBLEM REPORTING AND CORRECTIVE ACTION

The Contractor shall implement a process for Software Problem Reporting and Corrective Action that addresses reporting, analyzing and correcting software nonconformances throughout the development lifecycle. The system and database shall be accessible remotely via the web by HRVDM/HDV Project representatives.

After development and starting with the first use of a software component with the flight hardware, software nonconformances shall be reported and dispositioned through the Problem/Failure Reporting system used for flight hardware. There shall be a method of linkage, traceability, or cross-referencing of information between the Software Problem Reporting system and the HRVDM/HDV anomaly reporting system.

5.6 GFE, EXISTING AND PURCHASED SOFTWARE

For any Government provided software or firmware, the Contractor shall ensure that the software meets the functional, performance and interface requirements placed upon it. The Contractor shall ensure that the software meets applicable standards, including those for design, code and documentation, or shall secure an HRVDM/HDV Project waiver to those standards.

5.7 SOFTWARE ASSURANCE STATUS REPORTING

Monthly status reports (DRD SW-16) shall be provided to the HRVDM/HDV Project.

5.8 NASA SURVEILLANCE OF SOFTWARE DEVELOPMENT

The Contractor shall allow NASA representatives and/or their designate/assignee to perform surveillance activities throughout the entire software development lifecycle.

5.2.3 Independent Verification and Validation

The Contractor shall provide all information required for the NASA Independent Verification and Validation (IV&V) effort to NASA IV&V Facility personnel. This includes, but is not limited to, access to all software reviews and reports, contractor plans and procedures, software code, software design documentation, and software problem reporting data. Wherever possible, the Contractor shall permit electronic access to the required information or furnish soft copies of requested information to GSFC and to NASA IV&V personnel.

5.3 REVIEWS

5.3.1 Software Reviews

The Contractor shall conduct the following formal software reviews:

1. Software Requirements Review (SWRR).
2. Software Preliminary Design Review (SWPDR).
3. Software Critical Design Review (SWCDR).
4. Software Test Readiness Review (SWTRR).
5. Software Acceptance Review (SWAR).

If software is addressed as part of the formal system-level reviews (e.g. SRR, PDR, or CDR), the Contractor shall adhere to the review criteria provided by the GSFC Systems Review Office (see Chapter 9).

5.3.2 Engineering Peer Reviews

The Contractor shall implement a program of engineering peer reviews (e.g., design walkthroughs or code inspections) throughout the software development lifecycle to identify and resolve concerns prior to formal system/subsystem level reviews. These reviews shall be commensurate with the scope, complexity, and acceptable risk of the software system/product.

Action items or Requests for Action (RFAs) from engineering peer reviews shall be recorded, maintained, and tracked throughout the development lifecycle.

5.4 SOFTWARE CONFIGURATION MANAGEMENT

The Contractor shall develop, document (DRD SW-01), and implement a Software Configuration Management (SCM) system that provides baseline management and control of software requirements, design, source code, data, and documentation.

The Contractor shall create and maintain a Software Configuration Control Board (SWCCB) to manage, assess, and control all changes. An HRVDM/HDV Project representative shall co-chair the SWCCB. The SWCCB shall classify each proposed software change as either a Class I or Class II change. Any changes classified as Class I per the definition below shall be forwarded to the HRVDM/HDV Project for disposition and approval. Any changes classified as Class II shall be handled by the Contractor and forwarded to the HRVDM/HDV Project for review and concurrence.

6.0 RESERVED

7.0 RISK MANAGEMENT REQUIREMENTS

This chapter addresses the Continuous Risk Management (CRM) requirements for the HRVDM/HDV Project.

7.1 GENERAL REQUIREMENTS

The Contractor shall document and conduct a project-specific CRM process

7.2 PROBABILISTIC RISK ASSESSMENT

The implementation of the CRM process shall include the use of tools and methodologies to support the qualitative and quantitative assessment of risk inherent in the system design and associated development and operations activities. Risk assessments are conducted as part of the system design, analysis and trade study activities. The results of these risk assessments shall be used to support project management decisions with respect to safety and mission success, and programmatic commitments.

Comparative numerical reliability assessments and/or reliability predictions, such as Probabilistic Risk Assessment (PRA) should be employed to:

a. Evaluate alternative design concepts, redundancy or cross- and other reliability goals and requirements as applicable strapping approaches, and part substitutions

b. Identify the elements of the design that are the greatest detractors of system reliability

c. Identify those potential mission limiting elements and components that will require special attention in part selection, testing, environmental isolation, and/or special operations

d. Assist in evaluating the ability of the design to achieve the mission life requirement

e. Evaluate the impact of proposed engineering change and waiver requests on reliability

The Contractor shall perform Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) described in Chapter 4 of this document. The results of FMEA, FTA and any numerical reliability assessments or predictions shall be reported at system-level critical milestone reviews. The presentations shall include descriptions of how the analysis was used to perform design trade-offs and how the results were taken into consideration when making design or risk management decisions.

7.3 RISK LIST

The Contractor shall maintain a Risk List throughout the project life cycle, along with programmatic impacts. The list should indicate which risks have the highest probability, which have the highest consequences, and which risks represent the greatest risk to mission success. The list should also identify actions being taken to address each specific risk. The Risk List shall be configuration controlled.

Risk status shall be communicated on a regular basis to the entire project team and customers

8.0 TECHNICAL REVIEW REQUIREMENTS

The Contractor shall support a comprehensive set of independent design reviews that are conducted by the GSFC Systems Review Office (SRO). The reviews cover all aspects of flight and ground hardware, software, and operations for which the Contractor has responsibility. In addition, each Contractor shall conduct a program of planned, scheduled and documented component and subsystem reviews of all aspects of his or her area of responsibility.

8.1 GENERAL

For each specified system-level review conducted by the GSFC SRO, the Contractor shall:

a. Develop and organize material for oral presentation to the GSFC review team. Copies of the presentation material will be available at each review.

b. Support splinter review meetings resulting from the major review.

c. Produce written responses to recommendations and action items resulting from the review.

d. Summarize, as appropriate, the results of the Contractor reviews at the component and subsystem level.

8.2 REVIEWS

The Contractor shall support the following formal GSFC reviews:

a. System Requirements Review (SRR)
b. Preliminary Design Review (PDR)
c. Critical Design Review (CDR
d. Mission Operations Review (MOR)
e. Pre-Environmental Review (PER) or Test Readiness Review (TRR)
f. Flight Operations Review (FOR)
g. Pre-Ship Review (PSR)
h. Launch Readiness Review (LRR)

9.0 DESIGN VERIFICATION REQUIREMENTS

This chapter addresses the design verification requirements for the HRVDM/HDV Project.

9.1 GENERAL

The Contractor shall conduct a verification program to ensure that the flight system meets the specified mission requirements. The program shall consist of functional demonstrations, analytical investigations, physical measurements and tests that simulate all expected environments. The Contractor shall provide adequate verification documentation including a verification plan and matrix, environmental test matrix and verification procedures. The verification documentation shall be available at all reviews.

GEVS-SE, Rev A shall be used as a baseline guide for developing the verification program. The GEVS-SE document is available at: http://arioch.gsfc.nasa.gov/302/gevs-se/toc.htm. Alternative methods are acceptable provided that the net result demonstrates compliance with the intent of the requirements.

9.2 DOCUMENTATION REQUIREMENTS

The following documentation shall be developed.

9.2.1 System Performance Verification Plan

A System Performance Verification Plan shall be prepared and define the tasks and methods required to determine the ability of the system to meet each project-level performance requirement (structural, thermal, optical, electrical, guidance/control, Radio Frequency (RF)/telemetry, science, mission operational, etc.) and to measure specification compliance. Limitations in the ability to verify any performance requirement shall be addressed, including the addition of supplemental tests and/or analyses that will be performed and a risk assessment of the inability to verify the requirement.

The plan shall address how compliance with each specification requirement will be verified. If verification relies on the results of measurements and/or analyses performed at lower (or other) levels of assembly, this dependence shall be described.

The following documents may be included as part of the System Performance Verification Plan or as separate documents.

9.2.2 Environmental Verification Plan

An Environmental Verification Plan shall be prepared to prescribe the tests and analyses that will collectively demonstrate that the hardware and software comply with the environmental verification requirements.

The Environmental Verification Plan shall provide the overall approach to accomplishing the environmental verification program. For each test, it shall include the level of assembly, the configuration of the item, objectives, facilities, instrumentation, safety considerations, contamination control, test phases and profiles, necessary functional operations, personnel responsibilities and requirement for procedures and reports. It shall also define a rationale for retest determination that does not invalidate previous verification activities. When appropriate, the interaction of the test and analysis activity shall be described.

Limitations in the environmental verification program that preclude the verification by test of any system requirement shall be documented. Alternative tests and analyses shall be evaluated and implemented as appropriate, and an assessment of project risk shall be included in the System Performance Verification Plan.

9.2.3 System Performance Verification Matrix

A System Performance Verification Matrix shall be prepared and maintained, to show each specification requirement, the reference source (to the specific paragraph or line item), the method of compliance, applicable procedure references, results, report reference numbers, etc. This matrix shall be included in the system review data packages showing the current verification status as applicable.

9.2.4 Environmental Test Matrix

As an adjunct to the system/environmental verification plan, an environmental test matrix (ETM) shall be prepared that summarizes all tests that will be performed on each component, each subsystem or instrument, and the payload.

A complementary matrix shall be kept showing the tests that have been performed on each component, subsystem, instrument or payload (or other applicable level of assembly). This shall include tests performed on prototypes or engineering units used in the qualification program and shall indicate test results (pass/fail or malfunctions). This matrix shall be included in the system review data packages showing the current verification status as applicable.

9.2.5 Environmental Verification Specification

An environmental verification specification shall be prepared that defines the specific environmental parameters that each system element is subjected to either by test or analysis in order to demonstrate its ability to meet the mission performance requirements. Such things as payload peculiarities and interaction with the launch vehicle shall be taken into account.

9.2.6 Performance Verification Procedures

For each verification test activity conducted at the component, subsystem, and payload levels of assembly, a verification procedure shall be prepared that describes the configuration of the test article, how each test activity contained in the verification plan and specification will be implemented.

Test procedures shall contain details such as instrumentation monitoring, facility control sequences, test article functions, test parameters, pass/fail criteria, quality control checkpoints, data collection, and reporting requirements. The procedures also shall address safety and contamination control provisions.

9.2.7 Verification Reports

After each component, subsystem, payload, and verification activity has been completed, a report shall be prepared. For each analysis activity, the report shall describe the degree to which the objectives were accomplished, how well the mathematical model was validated by related test data, and other such significant results. In addition, as-run verification procedures and all test and analysis data shall be retained for review.

9.2.8 System Performance Verification Report

At the conclusion of the verification program, a final system Performance Verification Report shall be delivered comparing the hardware/software specifications with the final verified values (whether measured or computed).

10.0 WORKMANSHIP STANDARDS

The Contractor shall plan and implement a Workmanship Program to assure that all electronic packaging technologies, processes and workmanship activities selected and applied meet mission objectives for quality and reliability. See Chapter 15 for additional information on electrostatic discharge (ESD) control

10.1 APPLICABLE DOCUMENTS

The current status and/or any application notes for these standards can be obtained at Uniform Resource Locator (URL): http://workmanship.nasa.gov/. The most current version of these standards shall be used for new procurements. However, if a specific revision is listed for a referenced standard, it is that revision only that is approved for use unless otherwise approved by project management.

- Conformal Coating and Staking: NASA-STD-8739.1, "Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies".
- Soldering – Flight, Surface Mount Technology: NASA-STD-8739.2, "Surface Mount Technology".
- Soldering – Flight, Manual (hand): NASA-STD-8739.3, "Soldered Electrical Connections".
- Soldering – Ground Systems: Association Connecting Electronics Industries (IPC)/Electronics Industry Alliance (EIA) J-STD-001C, "Requirements for Soldered Electrical and Electronic Assemblies".
- Electronic Assemblies – Ground Systems: IPC-A-610, "Acceptability of Electronic Assemblies".
- Crimping, Wiring, and Harnessing: NASA-STD-8739.4, "Crimping, Interconnecting Cables, Harnesses, and Wiring".
- Fiber Optics: NASA-STD-8739.5, "Fiber Optic Terminations, Cable Assemblies, and Installation".
- ESD Control: ANSI/ESD S20.20, "Protection of Electrical and Electronic Parts, Assemblies and Equipment" (excluding electrically initiated explosive devices).
- Printed Wiring Board (PWB) Design:
  - IPC-2221, "Generic Standard on Printed Board Design".
  - IPC-2222, "Sectional Design Standard for Rigid Organic Printed Boards".
  - IPC-2223, "Sectional Design Standard for Flexible Printed Boards".
  - IPC D-275 "Design Standard for Rigid Printed Boards and Rigid Printed Board Assemblies".
- PWB Manufacture:
  - IPC A-600, "Acceptability of Printed Boards".
  - IPC-6011, "Generic Performance Specification for Printed Boards".
  - IPC-6012, "Qualification and Performance Specification for Rigid Printed Boards"

  - Flight Applications – Supplemented with: GSFC/S312-P-003, Procurement Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses
- IPC-6013 "Qualification and Performance Specification for Flexible Printed Boards".
- IPC-6018 "Microwave End Product Board Inspection and Test."

10.2 DESIGN

10.2.1 Printed Wiring Boards

The PWB manufacturing and acceptance requirements identified in this chapter are based on using PWBs designed in accordance with the PWB design standards referenced above. Space flight PWB designs shall not include features that prevent the finished boards from complying with the Class 3 requirements of the appropriate manufacturing standard (e.g., specified plating thickness, internal annular ring dimensions, etc.).

10.2.2 Assemblies

The design considerations listed in the NASA workmanship and IPC standards listed above should be incorporated to the extent practical.

10.2.3 Ground Data Systems that Interface with Space Flight Hardware

GDS assemblies (this includes ground support equipment) that interface directly with space flight hardware shall be designed and fabricated using space flight parts, materials and processes for any portion of the assemblies that mate with the flight hardware; or that will reside with the space flight hardware in environmental chambers or other test facilities that simulate a space flight environment (e.g., connectors, test cables, etc.).

10.3 WORKMANSHIP REQUIREMENTS

10.3.1 Training and Certification

All personnel working on flight hardware shall be certified as having completed the required training, appropriate to their involvement, as defined in the above standards or, when approved by project management, in the Contractor's quality manual.

10.3.2 Flight and Harsh Environment Ground Systems Workmanship

10.3.2.1 Printed Wiring Boards

PWBs shall be manufactured in accordance with the Class 3 requirements in the above referenced IPC PWB manufacturing standards and GSFC/S312-P-003, "Procurement Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses". The Contractor shall provide PWB test coupons to the GSFC Materials Engineering Branch

(MEB) or a GSFC/MEB approved laboratory for evaluation. Coupon acceptance shall be obtained prior to population of flight PWBs.

10.3.2.2 Assemblies

Assemblies shall be fabricated using the appropriate workmanship standards listed above (i.e., NASA-STD-8739.3 for hand soldering; NASA-STD-8739.4 for crimping/cabling; NASA-STD-8739.5 for fiber optic termination and installation; NASA-STD-8739.2 for Surface Mount Soldering, etc.) and ANSI/ESD S20.20.

10.4 NEW OR ADVANCED MATERIALS AND PACKAGING TECHNOLOGIES

New and/or existing advanced materials and packaging technologies (e.g., multi-chip modules (MCMs), stacked memories, chip on board (COB), ball grid array (BGA), etc.) shall be reviewed and approved by the Parts Control Board defined in Section 12.2.

10.5 HARDWARE HANDLING

The Contractor shall use proper safety, ESD control and, where appropriate, cleanroom practices when handling flight hardware. The electrostatic charge generation and contamination potential of materials, processes, and equipment (e.g., cleaning equipment, packaging materials, purging, tent enclosures, etc.) shall be addressed.

11.0 PARTS REQUIREMENTS

This chapter addresses the Parts Requirements for the HRVDM/HDV Project.

11.1 GENERAL

The Contractor shall plan and implement an Electrical, Electronic, and Electromechanical (EEE) Parts Control Program to assure that all parts selected for use in flight hardware meet mission objectives for quality and reliability. The program shall be in place in time to effectively support the design and selection processes.

All parts shall be selected, processed and derated in accordance with GSFC EEE-INST-002, "Instructions for EEE Parts Selection, Screening, Qualification and Derating" for part quality level 1. For those parts not readily available as part quality level 1 but are available at part quality level 2, the parts will require appropriate additional testing to bring them into level 1 compliance.

The Contractor shall control the selection, application, evaluation, and acceptance of all parts through a Parts Control Board (PCB), or another documented system of parts control that is approved by the HRVDM/HDV project.

11.2 PARTS CONTROL BOARD (PCB)

The Contractor shall establish a Parts Control Board (PCB) or a similar documented system to facilitate the management, selection, standardization, and control of parts and associated documentation for the duration of the contract. The PCB shall be responsible for the review and approval of all EEE parts, for conformance to established criteria (including radiation effects), and for developing and maintaining a Program Approved Parts List (PAPL). The PCB is responsible for all parts activities such as failure investigations, disposition of non-conformances, and problem resolutions.

If there are any parts issues that cannot be resolved at the PCB level, the issues shall be referred to the HST SAM and the HRVDM/HDV Project Manager for resolution and disposition.

11.2.1 PCB Meetings and Notification

PCB meetings shall be convened on a regular basis or as needed. The GSFC HST Project Parts Engineer will participate in all PCB meetings and shall be notified in advance of all upcoming meetings. The Contractor shall maintain meeting minutes or records to document all decisions made and an electronic copy provided to GSFC within five working days of convening the meeting. GSFC will retain the right to overturn decisions involving nonconformances within five working days after receipt of meeting minutes.

11.2.2 PCB Membership

As a minimum, the PCB membership shall consist of the Contractor, Subcontractors, GSFC HST Project Parts Engineer (PPE) and GSFC Spacecraft Radiation Engineer (RE). The Contractor PPE and GSFC HST Project Parts Engineer will participate in all PCB meetings. The HST Systems Assurance Manager (SAM) (or delegate) will attend as necessary. The GSFC HST Project Parts Engineer (PPE) and GSFC Radiation Engineer (RE) will be permanent working and voting members of the PCB. The Contractor, and Subcontractors PPE shall assure that the appropriate individuals with engineering knowledge and skills are represented as necessary at meetings, such as part commodity specialists, Radiation Engineers or the appropriate subsystem design engineer.

11.3 PART SELECTION AND PROCESSING

Parts selected from the NASA Parts Selection List (NPSL) for quality level 1 are preferred. All other EEE parts shall be selected, manufactured, processed, screened, and qualified, as a minimum, to the level 1 requirements of GSFC EEE-INST-002.

11.4 CUSTOM OR ADVANCED TECHNOLOGY DEVICES.

Devices such as custom hybrid microcircuits, detectors, ASICs, and MCMs shall also be subject to parts control and include a design review appropriate for the individual technology. The design review shall address items such as element analysis and, when necessary. A Customer Source Inspection may be required.

11.5 PLASTIC ENCAPSULATED MICROCIRCUITS (PEMS)

The use of Plastic Encapsulated Microcircuits and plastic semi-conductors is discouraged. However, when use is necessary to achieve unique requirements that cannot be found in hermetic high reliability microcircuits, plastic encapsulated parts, must meet the requirements of NASA GSFC Supplement to GFSC EEE-INST-002, INSTRUCTIONS FOR PLASTIC ENCAPSULATED MICROCIRCUITS (PEMs) SELECTION, SCREENING AND QUALIFICATION. The PCB shall review the procurement specification for appropriate testing, and also review application, procurement and storage processes for the plastic encapsulated part(s) to assure that all aspects of the GSFC policy have been met. The PCB may grant

Preliminary Approval when the GSFC requirements have been met. Final approval for the use of the PEM(s) shall be obtained from the HRVDM/HDV Program Office.

11.6 DERATING

All EEE parts shall be used in accordance with the derating guidelines of GSFC EEE-INST-002. The Contractor's derating policy may be used in place of the guidelines and shall be submitted with the Contractors PCP. The Contractor shall maintain documentation on parts derating analysis and make it available for GSFC review. Compliance with parts derating shall be demonstrated at spacecraft qualification temperatures.

11.7 RADIATION REQUIREMENTS FOR PART SELECTION

All parts shall be selected to perform their function in their intended application for a 2X mission radiation dose based on The Radiation Environment for the HRVDM/HDV Project, and any associated analyses. The radiation environment poses three main risks to active parts that must be considered during part selection as identified below.

11.7.1 Total Ionizing Dose (TID)

TID including Enhanced Low Dose Rate (ELDR) effects. Parts shall be selected to ensure their adequate performance in the application up to a dose of 2x the expected mission dose. Linear bipolar parts shall be assumed to be ELDR susceptible unless the parts have been successfully tested and shown to be in sensitive.

11.7.2 Displacement Damage

Parts shall be selected to ensure their adequate performance in the application up to a dose of 2x the expected mission displacement damage dose.

11.7.3 Single Event Effects (SEE)

The contractor shall carry out an analysis documenting the consequences of single-event induced error modes to the part, circuit, subsystem, system and spacecraft. In particular, the analysis shall consider the consequences of Single Event Upset (SEU) or Single Event Transient (SET) in each application of the part. Parts susceptible to Single Event Latch up (SEL) should be avoided.

11.8 PART ANALYSIS

11.8.1 Destructive Physical Analysis

A sample of each lot date code of microcircuits, hybrid microcircuits, EMI filters, relays, capacitors, oscillators, and semiconductor devices shall be subjected to a Destructive Physical Analysis (DPA) as determined by the PCB.

11.8.2 Failure Analysis

The Contractor shall perform part Failure Analysis essential to achieve a timely resolution and closeout of each failure incident. The Contractor PPE shall submit the completed EEE part failure report with all supporting data, analyses, and photographs to the PCB for review and approval.

11.9 Parts Age and Storage Control

All parts procured with date codes indicating that more than five (5) years have elapsed from the date of manufacture to date of procurement shall be subjected to a re-screen and sample DPA per PCB recommendation. Alternate test plans may be used as approved by the PCB on a case-by case basis. Parts taken from user inventory older than 5 years do not require re screen, provided they have been properly stored. Parts over 10 years from the date of manufacture to date of procurement or stored in other than controlled conditions where they are exposed to the elements or sources of contamination shall not be used.

11.10 Parts Used in Off-the-Shelf Assemblies

Units or assemblies that are purchased as "off-the-shelf" hardware items shall be subjected to an evaluation of the parts used within them. The parts shall be evaluated for screening compliance to GSFC EEE-INST-002, established reliability level, and include a radiation analysis. Units may be required to undergo modification for use of higher reliability parts or Radiation hardened parts. All parts shall be subject to PCB approval.

Modifications such as additional shielding for radiation effectiveness or replacing radiation soft parts for radiation hardened parts may be required and shall be subject to RE approval.

11.11 VALUE ADDED TESTING

The following value added tests provide for enhanced reliability of parts and all additional testing shall be noted in the PAPL. Unless otherwise specified, testing shall be in accordance with the test methods referenced in GSFC EEE-INST-002.

11.11.1 Particle Impact Noise Detection (PIND)

All EEE devices with internal cavities (transistors, microcircuits, hybrids, relays and switches) shall be subjected to Particle Impact Noise Detection (PIND) screening, in accordance with the applicable specification. Any device failing this screen shall not be used in any flight application.

11.11.2 Capacitors

11.11.2.1 Surge Current Screening for Tantalum Capacitors

All solid tantalum capacitors used in filtering applications shall be subjected to surge current screening. Chip devices (CWR06 for example) shall receive testing in accordance with MIL-PRF-55365 (+25°C only). This testing can be performed at the manufacturer's facilities by adding an "A" suffix to the standard military part number. Leaded devices (M39003/01 for example) shall receive testing in accordance with MIL-PRF-39003/10.

11.11.2.2 Dielectric Screening for Ceramic Capacitors

Ceramic capacitors used in circuits at or below 10V shall be rated at 100V or greater except as follows. Each lot of capacitors rated below 100V, shall have samples subjected to Humidity Steady State Low Voltage testing (85°C and 85% relative humidity) in accordance with MIL-PRF-123 (12 piece sample for each lot/date code). Following humidity exposure, a Destructive Physical Analysis (DPA) shall be performed in accordance with MIL-PRF-123 (sample size per GSFC S-311-M-70, for each lot/date code) prior to acceptance.

11.11.3 Screening for Magnetic Components

Magnetic devices (transformers and inductors) shall be assembled and screened to the requirements of MIL-STD-981 (Design, Manufacturing and Quality Standards for Custom

Electromagnetic Devices for Space Applications) for class S devices. Burn-in screening shall be considered based on vendor history, performance stability requirements, device complexity, and application criticality.

Simple toroidal coils with one layer of windings may be exempted from burn in unless required by the core manufacturer to stabilize its properties, and such decisions require PCB documentation and approval.

11.12 PARTS LIST

The Contractor shall create and maintain a Program Approved Parts List (PAPL) and Parts Identification List_(PIL) for the duration of the program. Clear distinctions shall be made as to parts approval status and whether parts are planned for use in flight hardware. Parts must be approved for listing on the PAPL and PIL before initiation of procurement activity.

11.12.1Program Approved Parts List (PAPL)

The PAPL shall be the only listing of approved parts for flight hardware, and as such may contain parts not actually in flight design. Only parts that have been evaluated and approved by the PCB shall be listed in the PAPL. The PCB shall assure standardization and the maximum use of parts listed in the PAPL. (See Table 12-1)

11.12.2Parts Identification List (PIL)

The PIL shall list all parts proposed for use in flight hardware. The PIL is prepared from design team inputs or subcontractor inputs, to be used for presenting candidate parts to the PCB. The PIL shall include as a minimum the following information: part number, part name or description, manufacturer, manufacturer's generic part number, drawing number, specifications, comments as necessary to indicate problems, long lead times, additional testing imposed, application unique notes, etc.

11.12.3As-Designed Parts List (ADPL)

The Contractor PPE shall establish an As-Designed Parts List (ADPL) as soon as practical after the preliminary release of designs for CDR. The GSFC PPE will maintain a copy in the NASA Electronics Parts database, and will work with the design teams to keep the list(s) current. (See Table 11-1) The Contractor shall submit the final version of the ADPL in accordance contract requirements.

11.12.4As-Built Parts List (ABPL)

An As-Built Parts List (ABPL) shall also be prepared and submitted with the hardware. The ABPL is generally a final compilation of all parts as installed in flight equipment, with additional "as-installed" part information such as manufacturer name, CAGE code, Lot-Date Code, part serial number (if applicable), quantity used and box or board location. The manufacturer's plant specific CAGE code is preferred, but if unknown, the supplier's general cage code is sufficient (See Table 11-1)

11.13 Alerts

The Contractor and sub-contractors shall be responsible for the review and disposition of all GIDEP Alerts for impact on parts proposed for flight use. In addition, any NASA Alerts and Advisories provided to the Contractor by GSFC shall be reviewed and dispositioned. Alert applicability, impact, and corrective actions shall be documented and delivered in accordance with the HRVDM/HDV Program requirements (see Chapter 15).

11.14 ADDITIONAL REQUIREMENTS

11.14.1Traceability

The Contractor shall utilize traceability database(s) that provide the capability to retrieve historical records of EEE parts from initial procurement and receipt through, storage, kiting, assembly, test, and final acceptance of the deliverable product. Also, the database shall permit the traceability to the procurement document and provide for:

1. Cross-referencing and traceability of part manufacturer and date code to the assembly traveler or production plan.
2. The storage of the accumulated data records.

All flight EEE parts shall be traceable to the date code or manufacturer's inspection lot, wafer lot (where applicable). Traceability shall be maintained throughout manufacturing for each deliverable item.

11.14.2Prohibited Metals

Pure tin plating shall not be used in the construction and surface finish of EEE parts proposed for space hardware. Only alloys containing less than 97% tin are acceptable.

The use of cadmium or zinc is prohibited in the construction and surface finish of space hardware. All cadmium alloys or zinc alloys (e.g. brass) shall be completely over plated with an approved metal.

11.14.3PCB Supplier and Manufacturer Surveillance (Monitoring)

The PCB shall establish a policy and procedures for the periodic surveillance and auditing of suppliers, vendors, laboratories and manufacturers to ensure compliance to procurement, quality, reliability and survivability requirements. Contractor's surveillance of laboratories, suppliers, vendors, and manufacturers that have been approved as a part of Qualified Parts List (QPL) or Qualified Manufacturer's List (QML) program for products listed in the space quality baseline is not required. When surveillance/audit data is available from other sources (e.g. other contractor programs, other contractor sub-contractors, independent audits reports, etc.) the contractor may utilize the results of the data contingent on the review and approval by the PCB. Acceptability of the data shall be based on technical considerations, as well as timeliness and confidence in the source of the data.

11.14.4Reuse of Parts and Materials

Parts and materials which have been installed in an assembly, and are then removed from the assembly for any reason, shall not be used again in any item of flight or spare hardware without prior approval of the PCB based on the submission of evidence that this practice does not degrade the system performance.

11.15 DATA REQUIREMENTS

General

Attributes (parametric test) summary data shall be available to GSFC for all testing performed. Variable data (read and record) shall be recorded for initial, interim and final electrical test points. Test data shall be available to GSFC.

For those parts potentially susceptible to radiation effects in the HRV environment, a summary radiation report that identifies parameter degradation behavior shall be provided to the PCB. Variable data acquired during radiation testing shall be available to GSFC.

11.15.1Retention of Data and Test Samples.

All builders of flight hardware shall have a method in place for retention of data generated for parts tested and used in flight hardware. The data shall be kept on file in order to facilitate future risk assessment and technical evaluation, as needed. In addition, the prime contractor and subcontractors shall retain all part functional failures, all destructive and non-flight non-destructive test samples, which could be used for future validation of parts for performance under certain conditions not previously accounted for. PIND test failures may be submitted for DPA, radiation testing or used in engineering models. Parts and data shall be retained for the useful life of the spacecraft, unless otherwise permitted by the PCB.

All historical quality records and those data required to support these records shall be retained for until end of contract completion.

11.15.2End Item Acceptance Package

The Contractor PPE and each Subcontractor PPE shall establish and maintain a EEE parts data package for each unit level assembly produced under the contract. The data package shall identify and include all applicable lower level part and subassembly data and provide test data to support assembly performance. Each package shall contain, as a minimum:

1. Manufacturing/inspection history; "As- designed'' to ''As- Built" parts list configuration comparison.
2. EEE part nonconformance documentation, including part failure reports, and waiver/deviation reports
3. Photographs, refer to section 12.18.3.
4. Dispositions for installed parts impacted by GIDEP alerts / NASA Problem Advisories, or purges; and, other data relevant to acceptance of the hardware.
5. All historical quality records and those data required to support these records shall be retained for a period of 20 years, or end of contract completion.

11.15.3Photographic Requirements

The Contractor shall provide a digital photographic record of each electronic PWB and subassembly. The photograph shall be of sufficient resolution to clearly show component placement, part marking, or details that are covered or obscured at subsequent levels of assembly and/or any other operation that renders subsequent inspection impractical. Photographs shall also be provided of the end item clearly showing all critical details.

Each photograph shall be identified with a label containing the following information: assembly number, serial number, description (e.g. name of the assembly), date of photo, and the supplier's company name. The subject shall appropriately fill the digital frame to allow for effective magnification. The image shall be of sufficient resolution to permit identification of components and verification of wire routings. The resolution shall also permit further enlargement of the image if required for analysis.

Photographic images shall be a minimum 6.0 Mega pixel digital image file. A complete set of photographs shall be included in each end item data package.

Table 11-1 Required Fields

Field	Required Field for Parts List Type		
	ADPL	PAPL	ABPL
Item Number	X	X	X
Spacecraft Name	X	X	X
Instrument Name	X	X	X
Generic Part Number	X	X	X
Procurement Part Number	X	X	X
Flight Part Number		X	X
Description	X	X	X
Package: Case Style and Number of Pins	X	X	X
Lot Date Code			X
Manufacturer	X	X	X
Cage Code	X	X	X
Distributor	X		
Additional Testing Required	X	X	
Quantity needed	X		X
Quantity Procured	X		

Radiation Hardness Evaluation: TID, Krads	X	X	X
Radiation Hardness Evaluation: SEL, MeV	X	X	X
Radiation Hardness Evaluation: SEU, MeV	X	X	X
Radiation Hardness Evaluation: Displacement Damage	X	X	X
Radiation Data Source: TID	X		
Radiation Data Source: SEE	X		
Notes	X		
PMCB Comments	X	X	
Approval Date	X	X	X
Box Identification	X	X	X
Part Location (Circuit Identifier)			X

12.0 MATERIALS SELECTION

This chapter addresses the Materials, Processes, and Lubrication Requirements for the HRVDM/HDV Project.

12.1 GENERAL REQUIREMENTS

The Contractor shall implement a comprehensive Materials, Processes and Lubrication plan In order to anticipate and minimize materials problems during space hardware development and operation. When selecting materials and lubricants, the Contractor shall consider potential problem areas such as radiation effects, thermal cycling, stress corrosion cracking, galvanic corrosion, hydrogen embrittlement, lubrication, contamination of cooled surfaces, composite materials, atomic oxygen, useful life, vacuum outgassing, toxic offgassing, flammability and fracture toughness, as well as the properties required by each material usage or application.

The HST Materials Assurance Engineer (MAE) must concur with all materials, lubricants and material processes used for the spaceflight hardware.

12.2 COMPLIANT MATERIALS

The Contractor shall use compliant materials in the fabrication hardware to the extent practicable. In order to be compliant, a material must be used in a conventional application and meet the applicable selection criteria identified below. A compliant material does not require an MUA.

1. Hazardous materials requirements, including flammability, toxicity and compatibility as specified in EWR 127-1 Range Safety Requirements2.
2. Vacuum Outgassing requirements as defined in paragraph 12.2.4.
3. Stress corrosion cracking requirements as defined in Marshall Space Flight Center MSFC-STD-3029.

12.2.1 Non-compliant Materials

A material that does not meet the above requirements, or meets the requirements, but is used in an unconventional application, will be considered to be a non-compliant material. The proposed use of a non-compliant material requires that a MUA be submitted to the HST MAE for approval.

12.2.2 Polymeric Materials

The Contractor shall prepare and submit a polymeric materials and composites usage list. The list shall be submitted to the HST MAE, in electronic format, for review and approval (see DID 12-1).

12.2.3 Flammability and Toxic Offgassing

Material flammability and toxic offgassing shall be determined in accordance with the test methods described in NASA-STD-6001. Payload materials shall meet the requirements of EWR 127-1 Range Safety Requirements.

12.2.4 Vacuum Outgassing

Material vacuum outgassing shall be determined in accordance with American Society for Testing of Materials (ASTM) E-595. In general only materials that have a total mass loss (TML) less than 1.00% and a collected volatile condensable mass (CVCM) less than 0.10% will be approved for use in a vacuum environment.

12.2.5 Shelf-Life-Controlled Materials

Polymeric materials that have a limited shelf-life shall be controlled by a process that identifies the start date (manufacturer's processing, shipment date, or date of receipt, etc.), the storage conditions associated with a specified shelf-life, and expiration date. Materials such as o-rings, rubber seals, tape, uncured polymers, lubricated bearings and paints shall be included. The use of materials whose date code has expired requires that the Contractor demonstrate, by means of appropriate tests, that the properties of the materials have not been compromised for their intended use. Such materials shall be approved by the HST MAE. When a limited-life piece part is installed in a subassembly, its usage shall be approved by the HST Materials Assurance Engineer.

12.2.6 Inorganic Materials

The Contractor shall prepare and document an inorganic materials usage list or the Contractor's equivalent. The list shall be submitted, in electronic form, to the HST Materials Assurance Engineer for review and approval (see DID 12-2). In addition, the Contractor may be requested to submit supporting applications data. The criteria specified in MSFC-STD-3029 shall be used to determine that metallic materials meet the stress corrosion cracking criteria. An MUA shall be submitted for each material usage that does not comply with the MSFC-STD-3029 requirements. Additionally, for the HST Materials Assurance Engineer to approve usage of individual materials, a stress corrosion evaluation form or an equivalent Contractor form or any/all of the information contained in the stress corrosion evaluation form may be required from the Contractor.

The use of tin, zinc, and cadmium platings in any flight application requires an MUA prior to use of that material.

12.2.7 Fasteners

As part of the parts and materials list approval process, the HST Materials Assurance Engineer will approve all flight fasteners. Towards this end, the Contractor shall provide all information needed by the HST Materials Assurance Engineer to ensure its ability to concur with the flightworthiness of flight fasteners. The Contractor shall comply with the procurement documentation and test requirements for flight hardware and critical ground support equipment fasteners contained in 541-PG-8072.1.2, GSFC Fastener Integrity Requirements.

12.2.8 Lubrication

The Contractor shall prepare and document a lubrication usage list or the Contractor's equivalent. The list shall be submitted to the HST Materials Assurance Engineer for review and approval. The Contractor may be requested to submit supporting applications data.

12.2.9 Process Selection

The Contractor shall prepare and document a material process utilization list. The list shall be submitted to the HST MAE for review and approval. A copy of any process shall be submitted for review upon request.

12.2.10Procurement Requirements

12.2.10.1 Purchased Raw Materials

Raw Materials purchased by the Contractor shall be accompanied by the results of nondestructive, chemical, and physical tests, or a Certificate of Compliance. This information need only be provided to GSFC when there is a direct question concerning the material's flightworthiness.

12.2.10.2 Raw Materials used in Purchased Products

The Contractor shall require that their suppliers meet the requirements of this Chapter and provide, upon request, the results of acceptance tests and analyses performed on raw materials.

13.0 CONTAMINATION CONTROL REQUIREMENS

This chapter addresses the Contamination Control Requirements for the HRVDM/HDV Project

13.1 General

The Contractor shall document and implement a contamination control program appropriate for the hardware. The program shall establish the specific cleanliness requirements and delineate the approaches to be followed.

13.2 CONTAMINATION CONTROL VERIFICATION PROCESS

The Contractor shall develop a contamination control verification process. The verification process shall be performed in order

a. Determination of contamination sensitivity;

b. Determination of a contamination allowance;

c. Determination of a contamination budget;

d. Development and implementation of a contamination control plan.

13.3 CONTAMINATION CONTROL PLAN (CCP)

The Contractor shall document the procedures that will be followed to control contamination. The CCP shall be provided to GSFC for review and approval.

13.4 MATERIAL OUTGASSING

In accordance with ASTM E595, NASA RP 1124 may be used as a guide. Individual material outgassing data shall be established based on each component's operating conditions. Established material outgassing data shall be verified and shall be reviewed by GSFC.

13.5 THERMAL VACUUM BAKEOUT

The Contractor shall perform thermal vacuum bakeouts of all hardware. The parameters of such bakeouts (e.g., temperature, duration, outgassing requirements, and pressure) must be individualized depending on materials used, the fabrication environment, and the established contamination allowance.

13.6 HARDWARE HANDLING

The Contractor shall practice cleanroom standards in handling hardware. The contamination potential of material and equipment used in cleaning, handling, packaging, tent enclosures, shipping containers, bagging (e.g., anti-static film materials), and purging shall be described in detail for each subsystem or component at each phase of assembly, integration, test, and launch.

14.0 ELECTROSTATIC DISCHARGE CONTROL

The Contractor shall document and implement an ESD Control Program in accordance with ANSI/ESD S20.20 to assure that all manufacturing, inspection, testing, and other processes will not compromise mission objectives for quality and reliability due to ESD events.

15.0 GIDEP ALERTS AND PROBLEM ADVISORIES

The Contractor shall participate in the GIDEP in accordance with the requirements of the GIDEP SO300- BT-PRO-010 and SO300-BU-GYD-010, available from the GIDEP Operations Center, Post Office (PO) Box 8000, Corona, California 92878-8000.

The Contractor shall review all GIDEP ALERTS, GIDEP SAFE-ALERTS, GIDEP Problem Advisories, GIDEP Agency Action Notices, NASA Advisories and any informally documented component issues presented by Code 303, to determine if they affect the Contractor products produced for NASA. For GIDEP ALERTS, GIDEP SAFE-ALERTS, GIDEP Problem Advisories, GIDEP Agency Action Notices and NASA Advisories that are determined to affect the program, the Contractor shall take action to eliminate or mitigate any negative effect to an acceptable level. The Contractor shall generate the appropriate failure experience data report(s) (GIDEP ALERT, GIDEP SAFE-ALERT, GIDEP Problem Advisory) on a monthly basis, in accordance with the requirements of GIDEP SO300-BT-PRO-010 and SO300-BU-GYD-010 whenever failed or nonconforming items, available to other buyers, are discovered during the course of the contract.

16.0 APPLICABLE DOCUMENTS LIST

DOCUMENT	DOCUMENT TITLE
ANSI/ASQC Q9000-3	Quality Management and Quality Assurance Standards – Part 3: Guidelines for the Application of ISO 9001 to the Development, Supply and Maintenance of Software
ANSI/ISO/ASQ Q9001:2000	American National Standard Quality Systems - Model for Quality Assurance in Design, Development, Production, Installation and Servicing
ANSI/ESD S20.20	ESD Association Standard for the Development of an Electrostatic Discharge Control Program for protection of electrical and electronic parts, assemblies, and equipment (excluding electrically initiated explosive devices).
ANSI/IPC-A-600	Acceptability of Printed Boards.
ASTM E-595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
EWR 127-1	Eastern and Western Range Safety Requirements
FAR	Federal Acquisition Regulations
GEVS-SE	General Environmental Verification Specification for STS and ELV Payloads, Subsystems and Components.
GMI 1700.2	Goddard Space Flight Center Health and Safety Program

GPG 8621.2	Processing Mishap, Incident, Hazard, and Close Call Reports
GPG 8621.3	Mishap, Incident, Hazard, and Close Call Investigation
GPG 8700.4	Technical Review Program
GPG 8700.6	Engineering Peer Reviews
GSFC S-312-P003	Procurement Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses
GSFC EEE-INST-002	Instructions for EEE Parts Selection, Screening, and Qualification and Derating
IEEE STD 610.12	IEEE Standard Glossary for Software Engineering Terminology
IEEE STD 730	IEEE Standard for Software Quality Assurance Plans
IEEE STD 982.2	IEEE Guide for the Use of IEEE Standard Dictionary of Measures to Produce Reliable Software
IPC A-600	Acceptability of Printed Boards
IPC-A-610	Acceptability of Electronic Assemblies
IPC D-275	Design Standard for Rigid Printed Boards and Rigid Printed Board Assemblies
IPC/EIA J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies

IPC-2221	Generic Standard on Printed Board Design
IPC-2222	Sectional Design Standard for Rigid Organic Printed Boards
IPC-2223	Sectional Design Standard for Flexible Printed Boards
IPC-6011	Generic Performance Specifications for Printed Boards
IPC-6012	Qualification and Performance Specification for Rigid Printed Boards
IPC-6013	Qualification and Performance Specification for Flexible Printed Boards
IPC-6018	Microwave End Product Board Inspection and Test
ISO 17025	General Requirements for the Competence of Testing and Calibration Laboratories
JSC 26943	Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports
KHB 1710.2	Kennedy Space Center Safety Practices Handbook
MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-470	Designing and Developing Maintainable Products and Systems
MIL-HDBK-472	Maintainability Prediction

MIL-STD-461	Electromagnetic Emission and Susceptibility Requirement for Control of Electromagnetic Interference
MIL-STD-756	Reliability Modeling and Prediction
MIL-STD-1629	Procedures for Performing a Failure Mode Effects and Criticality Analysis
MSFC CR 5320.9	Payload and Experiment Failure Mode Effects Analysis and Critical Items List Ground Rules
MSFC-HDBK-527	Material Selection List for Space Hardware Systems
MSFC-SPEC-522	Design Criteria for Controlling Stress Corrosion Cracking
NASA RP-1124	Outgassing Data for Selecting Spacecraft Materials
NASA RP-1161	Evaluation of Multi-layer Printed Wiring Boards by Metallographic Techniques
NHB 8060.1	Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion
NPD 8700.1	NASA Policy for Safety & Mission Success
NPD 8710.3	NASA Policy for Limiting Orbital Debris Generation
NPG 7120.5	NASA Program and Project Management Processes and Requirements

NPG 8000.4	Risk Management Procedures and Guidelines
NPG 8715.3	NASA Safety Manual
NASA-STD-2100-91	Software Documentation Standard
NASA-STD-2201-93	Software Assurance Standard
NASA-STD-2202-93	Software Formal Inspections Standard
NASA-STD-6001	Flammability, Odor, Off-gassing and Compatibility Requirements & Test Procedures for Materials in Environments that Support Combustion
NASA-STD 8719.13	NASA Software Safety Standard
NASA-STD 8719.14	Guidelines and Assessment Procedures for Limiting Orbital Debris
NASA-STD-8739.1	Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology
NASA-STD-8739.3	Workmanship Standard for Soldered Electrical Connections
NASA-STD-8739.4	Workmanship Standard for Crimping, Interconnecting Cables, Harnesses and Wiring

NASA-STD-8739.5	Workmanship Standard for Fiber Optic Terminations, Cable Assemblies and Installation
NSS 1740.13	NASA Software Safety Standard
NSS 1740.14	Guidelines and Assessment Procedures for Limiting Orbital Debris
NSTS 14046	Payload Verification
NSTS 22648	Flammability Configuration Analysis for Spacecraft Applications
NSTS/ISS 13830	Payload Safety Review and Data Submittal Requirements
NSTS/ISS 18798	Interpretations of NSTS/ISS Payload Safety Requirements
S-302-89-01	Procedures for Performing a Failure Mode and Effects Analysis
S-311-M-70	Specification for Destructive Physical Analysis
SAE AS9100	Aerospace Standard, Quality Systems Model for Quality Assurance, Design, Development, Production, Installation and Servicing
SAE JA1002	Software Reliability Program Standard
540-PG-8715.1.1	Mechanical Systems Division Safety Manual – Volume I
540-PG-8715.1.2	Mechanical Systems Division Safety Manual – Volume II

541-PG-8072.1.2	GSFC Fastener Integrity Requirements
5405-048-98	Mechanical Systems Center Safety Manual

17.0 ACRONYMS AND ABBREVIATIONS

Acronym/ Abbreviation	Definition
ABPL	As-Built Parts List
ADPL	As-Designed Parts List
ANSI	American National Standards Institute
AR	Acceptance Review
ASQC	American Society for Quality Control
ASIC	Application Specific Integrated Circuits
ASTM	American society for Testing of Materials
BGA	Ball Grid Array
BOL	Beginning of Life
CCP	Contamination Control Plan
CDR	Critical Design Review
CDRL	Contract Delivery Requirements List
COB	Chip on Board
COTS	Commercial off-the shelf
CPT	Comprehensive Performance Test
CVCM	Collected Volatile Condensable Mass
DID	Data Item Description
DM	De-orbit Module
DoD	Department of Defense
DPA	Destructive Physical Analysis
DRD	Data Requirements Description
DRP	Design Review Program
DRT	Design Review Team
EEE	Electrical, Electronic, and Electromechanical
EEPROMS	Electrically Erasable PROMS
ELDR	Enhanced Low Dose Rate
ELV	Expendable Launch Vehicle
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOL	End of Life

Acronym/ Abbreviation	Definition
ESD	Electrostatic Discharge
ETM	Environmental Test Matrix
EWR	Eastern and Western Range
FMEA	Failure Modes and Effects Analysis
FOR	Flight Operations Review
FPGA	Field Programmable Gate Array
FTA	Fault Tree Analysis
GDS	Ground Data Systems
GEVS	General Environmental Verification Specification
GEVS-SE	General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components
GFE	Government-Furnished Equipment
GIA	Government Inspection Agency
GIDEP	Government Industry Data Exchange Program
GMI	Goddard Management Instruction
GOTS	Government off-the-shelf
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HRVDM/HDV	Hubble Space Telescope Robotic Servicing and De-orbit Mission
HRV	Hubble Robotic Vehicle
IAC	Independent Assurance Contractor
ICD	Interface Control Document
IV&V	Independent Verification and Validation
JSC	Johnson Space Center
KHB	Kennedy Handbook
LPT	Limited Performance Test
LRR	Launch Readiness Review
MAE	Materials Assurance Engineer
MAG	Mission Assurance Guidelines
MAP	Mission Assurance Plan
MAR	Mission Assurance Requirements
MEB	Materials Engineering Branch
MCM	Multi-Chip Module
MO&DSD	Mission Operations and Data Systems Directorate

Acronym/ Abbreviation	Definition
MOR	Mission Operations Review
MOTS	Modified off-the-shelf
MRB	Material Review Board
MSFC	Marshall Space Flight Center
MSPSP	Missile System Pre-launch Safety Package
MSR	Management Status Report
MUA	Materials Usage Agreement
NAS	NASA Assurance Standard
NASA	National Aeronautics and Space Administration
NCR	Non Conformance Report
NF	NASA Form
NHB	NASA Handbook
NPD	NASA Policy Directive
NPG	NASA Procedures and Guidelines
NPSL	NASA Parts Selection List
NSS	NASA Safety Standard
NSTS	National Space Transportation System
OSHA	Occupational Safety and Health Administration
OSSMA	Office of Systems Safety and Mission Assurance
PAPL	Project Approved Parts List
PCB	Parts Control Board
PCP	Parts Control Plan
PEM	Plastic Encapsulated Microcircuits
PDR	Preliminary Design Review
PER	Pre-Environmental Review
PFR	Problem/Failure Report
PHA	Preliminary Hazard Analysis
PI	Principal Investigator
PIL	Parts Identification List
PIND	Particle Impact Noise Detection
POCC	Payload Operations Control Center
PPE	Project Parts Engineer
PPL	Preferred Parts List
PRA	Probabilistic Risk Assessment

Acronym/ Abbreviation	Definition
PROMS	Programmable Read Only Memories
PSR	Pre-Shipment Review
PWB	Printed Wiring Board
QML	Quality Manufacturer's List
QMS	Quality Management System
QPL	Quality Parts List
RFP	Request for Proposal
RE	Radiation Engineer
RF	Radio Frequency
RFA	Request For Action
RH	Relative Humidity
SAM	Systems Assurance Manager
SCC	Stress Corrosion Cracking
SCD	Source Control Drawing
SCM	Software Configuration Management
SCR	System Concept Review
SEE	Single Event Effects
SEL	Single Event Latch-up
SEU	Single Event Upset
SOCC	Simulations Operations Control Center
SOW	Statement of Work
SQMS	Software Quality Management System
SRO	Systems Review Office
SRR	Software Requirements Review
SSHA	Subsystem Hazard Analysis
SSPP	System Safety Program Plan
SWAR	Software Acceptance Review
SWCCB	Software Configuration Control Board
SWCDR	Software Critical Design Review
SWPDR	Software Preliminary Design Review
SWRR	Software Requirements Review
SWTRR	Software Test Readiness Review
TID	Total Ionizing Dose
TML	Total Mass Loss

Acronym/ Abbreviation	Definition
TRR	Test Readiness Review
URL	Uniform Resource Locator
V&V	Verification and Validation
VTL	Verification Tracking Log

18.0 DEFINITIONS

The following definitions apply within the context of this document:

Acceptance Tests: The validation process that demonstrates that hardware is acceptable for flight. It also serves as a quality control screen to detect deficiencies and, normally, to provide the basis for delivery of an item under terms of a contract.

Audit: A review of the Contractor's, contractor's or subcontractor's documentation or hardware to verify that it complies with project requirements.

Collected Volatile Condensable Material (CVCM): The quantity of outgassed matter from a test specimen that condenses on a collector maintained at a specific constant temperature for a specified time.

Configuration: The functional and physical characteristics of the payload and all its integral parts, assemblies and systems that are capable of fulfilling the fit, form and functional requirements defined by performance specifications and engineering drawings.

Configuration Control: The systematic evaluation, coordination, and formal approval/disapproval of proposed changes and implementation of all approved changes to the design and production of an item the configuration of which has been formally approved by the contractor or by the purchaser, or both.

Configuration Management: The systematic control and evaluation of all changes to baseline documentation and subsequent changes to that documentation which define the original scope of effort to be accomplished (contract and reference documentation) and the systematic control, identification, status accounting and verification of all configuration items.

Contamination: The presence of materials of molecular or particulate nature which degrade the performance of hardware.

Derating: The reduction of the applied load (or rating) of a device to improve reliability or to permit operation at high ambient temperatures.

Design Specification: Generic designation for a specification that describes functional and physical requirements for an article, usually at the component level or higher levels of assembly.

In its initial form, the design specification is a statement of functional requirements with only general coverage of physical and test requirements. The design specification evolves through the project life cycle to reflect progressive refinements in performance, design, configuration, and test requirements. In many projects the end-item specifications serve all the purposes of design specifications for the contract end-items. Design specifications provide the basis for technical and engineering management control.

Designated Representative: An individual (such as a NASA plant representative), firm (such as assessment contractor), Department of Defense (DOD) plant representative, or other government representative designated and authorized by NASA to perform a specific function for NASA. As related to the contractor's effort, this may include evaluation, assessment, design review, participation, and review/approval of certain documents or actions.

Destructive Physical Analysis (DPA): An internal destructive examination of a finished part or device to assess design, workmanship, assembly, and any other processing associated with fabrication of the part.

Discrepancy: See Nonconformance.

Design Qualification Tests: Tests intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch, and orbital operations. Their purpose is to uncover deficiencies in design and method of manufacture. They are not intended to exceed design safety margins or to introduce unrealistic modes of failure. The design qualification tests may be to either "prototype" or "protoflight" test levels.

Discrepancy: See Nonconformance

Electromagnetic Compatibility (EMC): The condition that prevails when various electronic devices are performing their functions according to design in a common electromagnetic environment.

Electromagnetic Interference (EMI): Electromagnetic energy that interrupts, obstructs, or otherwise degrades or limits the effective performance of electrical equipment.

Electromagnetic Susceptibility: Undesired response by a component, subsystem, or system to conducted or radiated electromagnetic emissions.

End-to-End Tests: Tests performed on the integrated ground and flight system, including all elements of the payload, its control, stimulation, communications, and data processing to demonstrate that the entire system is operating in a manner to fulfill all mission requirements and objectives.

Failure: A departure from specification that is discovered in the functioning or operation of the hardware or software. See nonconformance.

Failure Modes and Effects Analysis (FMEA): A procedure by which each credible failure mode of each item from a low indenture level to the highest is analyzed to determine the effects on the system and to classify each potential failure mode in accordance with the severity of its effect.

Flight Acceptance: See Acceptance Tests.

Fracture Control Program: A systematic project activity to ensure that a payload intended for flight has sufficient structural integrity as to present no critical or catastrophic hazard. Also to ensure quality of performance in the structural area for any payload (spacecraft) project. Central to the program is fracture control analysis, which includes the concepts of fail-safe and safe-life, defined as follows:

a. **Fail-safe:** Ensures that a structural element, because of structural redundancy, will not cause collapse of the remaining structure or have any detrimental effects on mission performance.

b. **Safe-life:** Ensures that the largest flaw that could remain undetected after non-destructive examination would not grow to failure during the mission.

Functional Tests: The operation of a unit in accordance with a defined operational procedure to determine whether performance is within the specified requirements.

Hardware: As used in this document, there are two major categories of hardware as follows:

a. **Prototype Hardware:** Hardware of a new design; it is subject to a design qualification test program; it is not intended for flight.

b. **Flight Hardware:** Hardware to be used operationally in space. It includes the following subsets:

(1) **Protoflight Hardware:** Flight hardware of a new design; it is subject to a qualification test program that combines elements of prototype and flight

acceptance validation; that is, the application of design qualification test levels and duration of flight acceptance tests.

(2) **Follow-On Hardware:** Flight hardware built in accordance with a design that has been qualified either as prototype or as protoflight hardware; follow-on hardware is subject to a flight acceptance test program.

(3) **Spare Hardware:** Hardware the design of which has been proven in a design qualification test program; it is subject to a flight acceptance test program and is used to replace flight hardware that is no longer acceptable for flight.

(4) **Re-flight Hardware:** Flight hardware that has been used operationally in space and is to be reused in the same way; the validation program to which it is subject depends on its past performance, current status, and the upcoming mission.

Inspection: The process of measuring, examining, gauging, or otherwise comparing an article or service with specified requirements.

Limit Level: The maximum expected flight.

Limited Life Items: Spaceflight hardware (1) that has an expected failure-free life that is less than the projected mission life, when considering cumulative ground operation, storage and on-orbit operation, (2) limited shelf life material used to fabricate flight hardware.

Margin: The amount by which hardware capability exceeds mission requirements

Material Review Board (MRB): The formal Contractor board established for the purpose of reviewing, evaluating, and disposing of specific nonconforming materials, supplies or services, and for ensuring the implementation and accomplishment of corrective action to preclude recurrence.

Monitor: To keep track of the progress of a performance assurance activity; the monitor need not be present at the scene during the entire course of the activity, but he will review resulting data or other associated documentation (see Witness).

Nonconformance: A condition of any hardware, software, material, or service in which one or more characteristics do not conform to requirements. As applied in quality assurance, nonconformances fall into two categories--discrepancies and failures. A discrepancy is a departure from specification that is detected during inspection or process control testing, etc., while the hardware or software is not functioning or operating. A failure is a departure from specification that is discovered in the functioning or operation of the hardware or software.

Nonconformance, critical. A nonconformance that judgment and experience indicate is likely to result in hazardous or unsafe conditions for individuals using, maintaining, or depending upon the supplies or services; or is likely to prevent performance of a vital agency mission.

Nonconformance, major. A nonconformance, other than critical, that is likely to result in failure, or to materially reduce the usability of the supplies or services for their intended purpose.

Nonconformance, minor. A nonconformance that is not likely to materially reduce the usability of the supplies or services for their intended purpose, or is a departure from established standards having little bearing on the effective use or operation of the supplies or services.

Offgassing: The emanation of volatile matter of any kind from materials into a manned pressurized volume.

Outgassing: The emanation of volatile materials under vacuum conditions resulting in a mass loss and/or material condensation on nearby surfaces.

Performance Validation: Determination by test, analysis, or a combination of the two that the payload element can operate as intended in a particular mission; this includes being satisfied that the design of the payload or element has been qualified and that the particular item has been accepted as true to the design and ready for flight operations.

Protoflight Testing: See Hardware.

Prototype Testing: See Hardware.

Qualification: See Design Qualification Tests.

Redundancy (of design): The use of more than one independent means of accomplishing a given function.

Repair: A corrective maintenance action performed as a result of a failure so as to restore an item to operate within specified limits.

Rework: Return for completion of operations (complete to drawing). The article shall be reprocessed to conform to the original specifications or drawings.

Similarity, Validation by: A procedure of comparing an item to a similar one that has been verified. Configuration, test data, application, and environment shall be evaluated. It should be determined that design-differences are insignificant, environmental stress will not be greater in the new application, and that manufacturer and manufacturing methods are the same.

Single Point Failure: A single element of hardware the failure of which would result in loss of mission objectives, hardware, or crew, as defined for the specific application or project for which a single point failure analysis is performed.

Temperature Cycle: A transition from some initial temperature condition to temperature stabilization at one extreme and then to temperature stabilization at the opposite extreme and returning to the initial temperature condition.

Temperature Stabilization: The condition that exists when the rate of change of temperatures has decreased to the point where the test item may be expected to remain within the specified test tolerance for the necessary duration or where further change is considered acceptable.

Thermal Balance Test: A test conducted to verify the adequacy of the thermal model, the adequacy of the thermal design, and the capability of the thermal control system to maintain thermal conditions within established mission limits.

Thermal-Vacuum Test: A test conducted to demonstrate the capability of the test item to operate satisfactorily in vacuum at temperatures based on those expected for the mission. The test, including the gradient shifts induced by cycling between temperature extremes, can also uncover latent defects in design, parts, and workmanship.

Torque Margin: Torque margin is equal to the torque ratio minus one.

Torque Ratio: Torque ratio is a measure of the degree to which the torque available to accomplish a mechanical function exceeds the torque required.

Total Mass Loss (TML): Total mass of material outgassed from a specimen that is maintained at a specified constant temperature and operating pressure for a specified time.

Validation: See Performance Validation.

Vibroacoustics: An environment induced by high-intensity acoustic noise associated with various segments of the flight profile; it manifests itself throughout the payload in the form of directly transmitted acoustic excitation and as structure-borne random vibration.

Waiver: A written authorization to accept an item that is found to depart from specific requirements, either during the manufacturing process or after having been submitted for Government inspection or acceptance but nevertheless is considered "acceptable as is", or after repair by an approved method.

Waiver, Critical Waiver: consists of acceptance of an item having a nonconformance with contract or configuration documentation involving safety.

Waiver, Major Waiver: consists of acceptance of an item having a nonconformance with contract or configuration documentation involving a) performance, b) interchangeability, reliability, survivability or maintainability, c) effective use or operation, d) weight or e) appearance.

Waiver, Minor Waiver: consists of acceptance of an item having a nonconformance with contract or configuration documentation which does not involve any of the factors listed in the above definition for a major waiver.

Workmanship Tests: Tests performed during the environmental validation program to verify adequate workmanship in the construction of a test item. It is often necessary to impose stresses beyond those predicted for the mission in order to uncover defects. Thus random vibration tests are conducted specifically to detect bad solder joints, loose or missing fasteners, improperly mounted parts, etc. Cycling between temperature extremes during thermal-vacuum testing and the presence of electromagnetic interference during EMC testing can also reveal the lack of proper construction and adequate workmanship.

Witness: A personal, on-the-scene observation of a performance assurance activity with the purpose of verifying compliance with project requirements (see Monitor).

19.0 DATA ITEM DESCRIPTIONS

19.1 DID 1-1: Mission Assurance Plan

Title: Mission Assurance Plan	CDRL No.: 1-1
Reference: Paragraph 1.1	
Use: Documents the Contractor's Mission Assurance Implementation approach.	
Related Documents: ANSI/ISO/ASQC Q9001: 1994, ANSI/ISO/ASQ Q9001:2000, SAE AS9100 and ISO 10013, SMR-5000	
Place/Time/Purpose of Delivery: Provide during development phase for GSFC review.	
Preparation Information: The plan shall address the Contractor's implementation of the HRVDM/HDV Mission Assurance Requirements. The following topics shall be addressed: 1. Configuration Management 2. System Safety 3. Reliability Assurance 4. Risk Management 5. Design Verification 6. Workmanship Standards 7. Electronic Parts Control 8. Materials Control 9. Contamination Control 10. ESD Protection 11. GIDEP Alerts	

19.2 DID 1-2: End Item Data Package

Title: End Item Data Package	CDRL No.: 1-2
Reference: Paragraph 1.4	
Use: Provides documented verification of the space-flight quality of delivered hardware.	
Related Documents: SMR-5000	
Place/Time/Purpose of Delivery: Provide for GSFC review at the Pre-Ship Review (PSR) and deliver to GSFC with the hardware.	

Preparation Information:

An End Item Data Package shall be provided for each delivered item or system. The format of the package shall be determined by the Contractor. The package shall include, but not limited to the following information:

1. As-Built hardware documentation describing accurately the configuration of each serialized assembly:
    a. Part number and revision of each item.
    b. Part description of each item.
    c. Procurement specification or SCD number
    d. Electronic part reference designation.
    e. Manufacturer.
    f. Parts, Materials, and Lubricant lists.
    g. Actual part markings
    h. Lot/Date Code (as applicable).
    i. Test lot number (as applicable)
    j. Wafer and lot number (as applicable)
    k. Serial number

2. Complete quality history of the items, including all manufacturing travelers.
3. Shortages list.
4. Operating times.
5. List of tests performed and results for each test.
6. Copies of all anomaly reports, both open and closed.
7. Deviations and Waivers.
8. MUAs
9. MRBs.
10. Evidence of Contractor QA acceptance.
11. Environmental test reports.
12. Closeout photographs.
13. Drawings, ICDs, etc.

In addition, the Contractor shall also determine and provide appropriate End Item Data Packages for delivered GSE systems.

19.3 DID 2-1: Quality Manual

Title: Quality Manual	CDRL No.: 2-1
Reference: Paragraph 2.0	
Use: Documents the Contractor's quality management system.	
Related Documents: ANSI/ISO/ASQC Q9001: 1994, ANSI/ISO/ASQ Q9001:2000, SAE AS9100 and ISO 10013.	
Place/Time/Purpose of Delivery: Provide with proposal for GSFC review. Provide Quality Manual updates to GSFC Project Office for review prior to implementation, or Provide with proposal for information along with evidence of third party certification/registration of the Contractor's quality management system by an accredited registrar.	
Preparation Information: Prepare a Quality Manual addressing all applicable requirements of relevant quality standard (Q9001, AS9100, etc). Refer to ISO 10013 for further guidelines on preparation of a quality manual. The Quality Manual shall contain: a. the title, approval page, scope and the field of application; b. table of contents; c. introductory pages about the organization concerned and the manual itself; d. the quality policy and objectives of the organization; e. the description of the organization, responsibilities and authorities, including the organization responsible for the EEE parts, materials, reliability, safety and test requirements implementation; f. a description of the elements of the quality system, Contractor policy regarding each element and Contractor implementation procedure for each clause or reference(s) to approved quality system procedures; system level procedures shall address the implementation of all requirements cited in this document. g. a definitions section, if appropriate;	

h. an appendix for supportive data, if appropriate.

Quality Manual distribution and changes shall be implemented by a controlled process. The Quality Manual shall be maintained/updated by the Contractor throughout the life of the contract.

19.4 DID 3-1: System Safety Program Plan

Title: System Safety Program Plan	CDRL No.: 3-1
Reference: Paragraph 3.2.1	
Use: The approved plan provides a formal basis of understanding between GSFC and the Contractor on how the System Safety Program will be conducted to meet the applicable launch range safety requirements. The approved plan shall account for all contractually required tasks and responsibilities on an item-by-item basis.	
Related Documents: a. EWR 127-1, Eastern Western Range System Safety Requirements b. NPG 7120.5, Program and Project Management Processes and Requirements c. NPD 8700.1, NASA Policy for Safety and Mission Success d. NSTS 1700.7B	
Place/Time/Purpose of Delivery: The Range User shall submit a draft SSPP to GSFC for review and approval within 45 days of contract award and a final at least 45 days prior to any program CDR.	
Product Preparation: The SSPP shall describe in detail tasks and activities of system safety management and system safety engineering required to identify, evaluate, and eliminate and control hazards, or reduce the associated risk to an acceptable level throughout the system life cycle.	

19.5 DID 3-2 Safety Assessment Report (SAR)

Title: Safety Assessment Report (SAR)	CDRL No.: 3-2
Reference: Paragraph 3.3	
Use: The Safety Assessment Report (SAR) is used to document a comprehensive evaluation of the mishap risk being assumed prior to the testing or operation of an instrument. The SAR will be provided to the spacecraft contractor as an input to their preparation of the Missile System Prelaunch Safety Package (MSPSP), which is one of the media through which missile system prelaunch safety approval is obtained.	
Related Documents: EWR 127-1, Eastern Western Range System Safety Requirements	
Place/Time/Purpose of Delivery: SAR delivery shall support the spacecraft contractor's MSPSP submittal schedule. The final MSPSP will be submitted to Range Safety at least 45 calendar days prior to hardware shipment to Range. Preliminary shipment will be TBD based on negotiation between the spacecraft contractor and the Range. GSFC will approve all deliveries/versions.	

Preparation Information:

The Safety Assessment Report will identify all safety features of the hardware, software, and system design as well as procedural, hardware, and software related hazards that may be present in the system being acquired. This includes specific procedural controls and precautions that should be followed. The safety assessment will summarize the following information:

1. The safety criteria and methodology used to classify and rank hazards plus any assumptions upon which the criteria or methodologies were based or derived including the definition of acceptable risk as specified by Range Safety
2. The results of analyses and tests performed to identify hazards inherent in the system including:
    a. Those hazards that still have a residual risk and the actions that have been taken to reduce the associated risk to a level contractually specified as acceptable
    b. Results of tests conducted to validate safety criteria, requirements, and analyses
3. The results of the safety program efforts including a list of all significant hazards along with specific safety recommendations or precautions required to ensure safety of personnel, property, or the environment. **NOTE:** The list shall be categorized as to whether or not the risks may be expected under normal or abnormal operating conditions.
4. Any hazardous materials generated by or used in the system
5. The conclusion, including a signed statement, that all identified hazards have been eliminated or their associated risks controlled to levels contractually specified as acceptable and that the system is ready to test or operate or proceed to the next acquisition phase
6. Recommendations applicable to hazards at the interface of Range User systems with other systems, as required

19.6 DID 3-3: Safety Data Package

Title: Safety Data Package (SDP)	CDRL No.: 3-3
Reference: Paragraph 3.4	
Use: Provide a detailed description of the payload design sufficient to support hazard analysis results, hazard analysis method, and other applicable safety related information. The Contractor shall include analyses identifying the ground operations hazards associated with the flight system, ground support equipment, and their interfaces. The Contractor shall take measures to minimize each significant identified hazard.	
Related Documents: a. EWR-127, Eastern Western Range System Safety Requirements b. KHB 1700.7, Space Shuttle Payload Ground Safety Handbook Note: Other launch range and launch vehicle requirements may apply	
Place/Time/Purpose of Delivery: In general provide preliminary (combined flight and ground safety package) with Preliminary Design Review (PDR) package, update at Critical Design Review (CDR), final 60 days before Pre Ship Review (PSR). * *(See applicable launch range and launch vehicle requirements for details).	

SAFETY DATA PACKAGE (cont)

Preparation Information:

The Safety Package shall include the following information:

1. Introduction. State, in narrative form, the purpose of the safety data package.

2. System Description. This section may be developed by referencing other program documentation such as technical manuals, System Program Plan, System Specification, etc.

   As applicable, either photos, charts, flow/functional diagrams, sketches, or schematics to support the system description, test, or operation.

3. System Operations.

a. A description or reference of the procedures for operating, testing and maintaining the system. Discuss the safety design features and controls incorporated into the system as they relate to the operating procedures.

b. A description of any special safety procedures needed to assure safe operations, test and maintenance, including emergency procedures.

c. A description of anticipated operating environments and any specific skills required for safe operation, test, maintenance, transportation or disposal.

d. A description of any special facility requirements or personal equipment to support the system.

SAFETY DATA PACKAGE (cont)

4. Systems Safety Engineering Assessment. This section shall include:

a. A summary or reference of the safety criteria and methodology used to classify and rank hazardous conditions.

b. A description of or reference to the analyses and tests performed to identify hazardous conditions inherent in the system.

   (1) A list of all hazards by subsystem or major component level that have been identified and considered from the inception of the program.

      a. A discussion of the hazards and the actions that have been taken to eliminate or control these items.

      b. A discussion of the effects of these controls on the probability of occurrence and severity level of the potential mishaps.

      c. A discussion of the residual risks that remain after the controls are applied or for which no controls could be applied.

      d. A discussion of or reference to the results of tests conducted to validate safety criteria requirements and analyses. These items shall be tracked and closed-out via a Verification Tracking Log (VTL).

SAFETY DATA PACKAGE (cont)

Preparation Information (continued):

5. Conclusions and Recommendations. This section shall include:
   a. A short assessment of the results of the safety program efforts. A list of all significant hazards along with specific safety recommendations or precautions required ensuring the safety of personnel and property.
   b. For all hazardous materials generated by or used in the system, the following information shall be included.
      (1) Materiel identification as to type, quantity, and potential hazards.
      (2) Safety precautions and procedures necessary during use, storage, transportation, and disposal.
      (3) A copy of the Material Safety Data Sheet (OSHA Form 20 or DD Form 1813) as required.
   c. Reference material to include a list of all pertinent references such as Test Reports, Preliminary Operating Manuals and Maintenance Manuals
   d. A statement signed by the Contractor System Safety Manager and the Program Manager certifying that all identified hazards have been eliminated or controlled and that the system is ready to test, operate, or proceed to the next acquisition phase. In addition, include recommendations applicable to the safe interface of this system with the other system(s).

6. The safety package shall be submitted for approval in accordance with the milestones required by the applicable launch site and launch vehicle safety regulation.

19.7 DID 3-4: Hazard Control Verification and Tracking

Title: Hazard Control Verification and Tracking	CDRL No.: 3-4
Reference: Paragraph 3.4	
Use: To provide a Hazard Control and Verification Tracking process or "closed-loop system" to assure safety compliance has been satisfied in accordance to applicable launch range safety requirements.	
Related Documents: a. EWR-127, Eastern Western Range System Safety Requirements b. KHB 1700.7, Space Shuttle Payload Ground Safety Handbook	
Place/Time/Purpose of Delivery: Provide hazard control verification and tracking system in accordance with applicable launch site range safety requirements. Documented methods of hazard controls shall be submitted with the initial SDP, MSPSP, or SAR and updated with each consecutive submittal. All open hazard control verification items must be closed in accordance with applicable launch site range safety requirements.	
Preparation Information: Provide documentation that demonstrates the process of verifying the control of all hazards by test, analysis, inspection, similarity to previously qualified hardware, or any combination of these activities. All verifications that are listed on the hazard reports shall reference the tests/analyses/inspections. Results of these tests/analyses/inspections shall be available for review and submitted in accordance with the contract schedule and applicable launch site range safety requirements.	

19.8 DID 3-5: Ground Operations Procedures

Title: Ground Operations Procedures	CDRL No.: 3-5
Reference: Paragraph 3.5	
Use: All ground operations procedures to be used at GSFC facilities, other integration facilities, or the launch site shall be submitted to GSFC for review and concurrence. Launch site ground operations procedures shall be submitted to applicable Range Safety 45 days prior to use.	
Related Documents: a. EWR-127, Eastern Western Range System Safety Requirements b. KHB 1710.2, Kennedy Space Center Safety Practices Handbook Note: Other launch vehicle and/or contractor, or commercial facility requirements may apply	
Place/Time/Purpose of Delivery: Provide preliminary 120 days prior to PSR, final 60 days before PSR, and submit to applicable Range Safety 45 days prior to use.	
Preparation Information: All hazardous operations as well as the procedures to control them shall be identified and highlighted. All launch site procedures shall comply with the applicable launch site safety regulation.	

19.9 **DID 3-6: Safety Nonconformance Requests**

Title: Safety Noncompliance Requests	CDRL No.: 3-6
Reference: Paragraph 3.6	
Use: The hardware Contractor shall submit to the HST Project Safety Manager (PSM) an associated safety noncompliance request that identifies the hazard and shows the rationale for approval of a noncompliance when a specific safety requirement cannot be met, as defined in the applicable launch site safety regulation. The request may require Range Safety concurrence for the noncompliance request to be approved.	
Related Documents: a. EWR-127, Eastern Western Range System Safety Requirements; b. KHB 1710.2, Kennedy Space Center Safety Practices Handbook	
Place/Time/Purpose of Delivery: As identified to the HST Project Safety Manager	
Preparation Information: The noncompliance request shall include the following information resulting from a review of each waiver or deviation request. a. A statement of the specific safety requirement and its associated source document name and paragraph number, as applicable, for which a waiver or deviation is being requested. b. A detailed technical justification for the exception. c. Analyses to show that the mishap potential of the proposed alternate requirement, method or process, as compared to the specified requirement. d. A narrative assessment of the risk involved in accepting the waiver or deviation. When it is determined that there are no hazards, the basis for such determination should be provided. e. A narrative on possible ways of reducing hazards severity and probability and existing compliance activities (if any). f. Starting and expiration date for waiver/deviation.	

19.10 DID 3-7: Orbital Debris Assessment

Title: Orbital Debris Assessment	CDRL No.: 3-7
Reference: Paragraph 3.8	
Use: Ensure NASA requirements for post mission orbital debris control are met.	
Related Documents: a. NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation b. NSS 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris	
Place/Time/Purpose of Delivery: Provide preliminary assessment prior PDR, updated package 45 days prior to CDR and a final package at PER	
Preparation Information: The assessment shall be done in accordance with NSS 1740.14, Guidelines and Assessment Procedures for Limiting Orbital Debris. The preliminary debris assessment should be conducted to identify areas where the program or project might contribute debris and to assess this contribution relative to the guidelines in so far as is feasible. Prior to CDR another debris assessment should be completed. This report should comment on changes made since the PDR report. The level of detail should be consistent with the available information of design and operations. When there are design changes after CDR that impact the potential for orbital debris generation, and update of the debris assessment report should be prepared, approved, and coordinated with the Office of System Safety and Mission Assurance. Orbital Debris Assessment Software is available for download from Johnson Space Center at URL: http://sn-callisto.jsc.nasa.gov/mitigate/das/das.html	

19.11 DID 12-1: Polymeric Materials and Composites Usage List

Title: Polymeric Materials and Composites Usage List	CDRL No.: 12-1
Reference: Paragraph 12.2.2	
Use: For usage evaluation and approval of all polymeric and composite materials applications.	
Related Documents: NASA RP-1124, ASTM E 595, MSFC-HDBK-527, NHB 1700.7, EWR 127.1 GMI 1700.3, NASA-STD-6001	
Place/Time/Purpose of Delivery: Provide to the HST MAE 30 days before Contractor PDR for review, 30 days before Contractor CDR for approval and 30 days before acceptance for approval.	

Preparation Information:

The Contractor shall provide the information requested on the polymeric materials and composites usage list form, the equivalent information on the Contractor's form or the equivalent information electronically. The form is in the Mission Assurance Guide.

The polymeric materials and composites usage list (1) form requires, as a minimum, the following information: spacecraft, subsystem or instrument name, GSFC technical officer, Contractor, address, prepared by, phone number, date of preparation, GSFC materials evaluator, evaluator's phone number, date received, date evaluated, item number, material identification (2), mix formula (3), cure (4), amount code, expected environment (5), outgassing values and reason for selection (6). Notes 1 through 6 are listed below:

1. List all polymeric materials and composites applications utilized in the system except lubricants that should be listed on polymeric and composite materials usage list.
2. Give the name of the material, identifying number and manufacturer Example: Epoxy, Epon 828, E. V. Roberts and Associates
3. Provide proportions and name of resin, hardener (catalyst), filler, etc. Example: 828/V140/Silflake 135 as 5/5/38 by weight
4. Provide cure cycle details. Example: 8 hrs. at room temperature + 2 hrs. at 150C
5. Provide the details of the environment that the material will experience as a finished S/C component, both in ground test and in space. List all materials with the same environment in a group. Example: T/V : -20C/+60C, 2 weeks, 10E-5 torr, ultraviolet radiation (UV)

   Storage: up to 1 year at room temperature

   Space: -10C/+20C, 2 years, 150 mile altitude, UV, electron, proton, atomic oxygen
6. Provide any special reason why the materials were selected. If for a particular property, please give the property. Example: Cost, availability, room temperature curing or low thermal expansion.

19.12 DID 12-2: Inorganic Materials and Composites Usage List

Title: Inorganic Materials and Composites Usage List	CDRL No.: 12-2
Reference: Paragraph 12.2.6	
Use: For usage evaluation and approval of all metal, ceramic and metal/ceramic composite material applications.	
Related Documents: MSFC-HDBK-527, NHB 1700.7, MSFC-SPEC-522	

Place/Time/Purpose of Delivery:

Provide to the GSFC Project Office 30 days before Contractor PDR for review, 30 days before Contractor CDR for approval and 30 days before acceptance for approval.

Preparation Information:

The hardware provider shall provide the information requested on the inorganic materials and composites usage list, the equivalent information on the hardware Contractor's forms or the equivalent information electronically.

The inorganic materials and composite usage list (1) form requires, as a minimum, the following information: spacecraft, subsystem or instrument name, GSFC technical officer, Contractor, Contractor address, prepared by, phone number, date of preparation, GSFC materials evaluator, evaluator's phone number, date received, item number, materials identification (2), condition (3), application or usage (4), expected environment (5), stress corrosion cracking table number, MUA number and NDE method. Notes 1 through 5 are listed below:

List all inorganic materials (metals, ceramics, glasses, liquids and metal/ceramic composites) except bearing and lubrication materials that should be listed on Form 18-59C.

Give materials name, identifying number manufacturer. Example:

a. Aluminum 6061-T6
b. Electroless nickel plate, Enplate Ni 410, Enthone, Inc
c. Fused silica, Corning 7940, Corning Class Works

Give details of the finished condition of the material, heat treat designation (hardness or strength), surface finish and coating, cold worked state, welding, brazing, etc. Example:

a. Heat-treated to Rockwell C 60 hardness, gold electroplated, brazed.
b. Surface coated with vapor deposited aluminum and magnesium fluoride
c. Cold worked to full hare condition, TIG welded and electroless nickel-plated.

Give details of where on the spacecraft the material shall be used (component) and its function. Example: Electronics box structure in attitude control system, not hermetically sealed.

Give the details of the environment that the material will experience as a finished S/C component, both in ground test and in space. Exclude vibration environment. List all materials with the same environment in a group. Example:

a. T/V: -20C/+60C, 2 weeks, 10E-5 torr, Ultraviolet radiation (UV)
b. Storage: up to 1 year at room temperature
c. Space: -10C/+20C, 2 years, 150 miles altitude, UV, electron, proton, Atomic Oxygen

Work Breakdown Structure (WBS)

for the

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

HST Robotic Vehicle (HRV) De-orbit Module (DM) Work Breakdown Structure (WBS)

This WBS shall be used to report cost for the design, develop, integrate and test of the DM as well as the cost to prepare for, launch, and operate the DM for the life of the mission. Figure 1 outlines the WBS.

1.0 Project Management

1.1 Resources Management
1.2 Schedule Management
1.3 Configuration Management
1.3.1 Document Management
1.3.2 Photographic and Video Documentation
1.4 Project Reviews
1.5 Travel
1.6 Contract and Procurement Management
1.7 Risk Management
1.8 Special Studies

2.0 Systems Engineering

2.1 Systems Engineering Management
2.2 Systems Engineering Design
2.2.1 Understanding the Requirements
2.2.2 Operations Concept Development
2.2.3 Architecture Design and Development
2.2.4 Requirements Identification and Management
2.2.5 Interfaces and ICDs
2.2.6 Mission Environments
2.3 Systems Engineering Implementation
2.3.1 Validation and Verification
2.3.2 Technical Resources Budget Tracking
2.3.3 Technical Risk Management

3.0 Electrical Systems

3.1 Electronic Parts and Radiation Effects
3.2 Power System
3.3 Command and Data Handling
3.4 Communications
3.5 Electrical System Accommodations

4.0 Mechanical Systems

5.0 Thermal Systems

5.1 DM Module Thermal System Design
5.2 DM Thermal Analyses
5.3 DM Thermal Interface Requirements
5.4 Design Verification
5.5 Thermal deliverables
5.6 Thermal Model Criteria
5.7 DM Module Thermal Testing

6.0 Guidance, Navigation and Control

6.1 GN&C Systems Engineering
6.2 Attitude Determination and Control System (ADCS)
6.3 Trajectory Design
6.4 Absolute Orbit Determination
6.5 Propulsion
6.6 Relative Navigation and Control System

7.0 Flight Sofware

7.1 Flight Software (FSW) Element
7.1.1 Planning and Requirements Life Cycle Activities
7.1.2 Design Life Cycle Activities
7.1.3 Implementation and Delivery Life Cycle Activities
7.1.4 Pre-Launch Sustaining Engineering through De-Orbit Activities
7.1.5 FSW V&V
7.2 Software Development and Validation (SDV) Software Element
7.2.1 Planning and Requirements Life Cycle Activities
7.2.2 Design Life Cycle Activities
7.2.3 Implementation and Delivery Life Cycle Activities
7.2.4 Pre-Launch Sustaining Engineering through De-Orbit Activities
7.2.5 SDV V&V
7.3 Software Management Requirements
7.4 Government Insight and Support of Government FSW Development
7.4.1 NASA IV&V Support
7.4.2 HRSDM Project EM FSW Development and V&V Support
7.5 Software Maintenance
7.6 Software Development, Validation, and Maintenance Environment
7.7 Software Development & Validation Facility (SDVF)

8.0 Integration, Test, and Verification

8.1 System Assembly and Integration
8.2 System Test
8.3 Mission-Level I&T
8.3.1 DM to EM and HST Interface Tests
8.3.2 DM Simulators

9.0 Mission Assurance

10.0 Launch Support

11.0 HST Interface

11.1 HST Battery Augmentation
11.2 HST Gyro Augmentation Support
11.3 HST Mechanical Interface

12.0 Ejection Module Interface

13.0 De-orbit Module Ground System Dev

13.1 Ground Segment and Operations Management
13.2 Ground Segment and Operations Systems Engineering
13.3 Ground System Hardware and Software
13.3.1 Ground System DMGTS
13.3.2 Ground Segment Trade Studies
13.3.3 Ground System DMGTS Network and Security
13.3.4 Ground System TDRSS Scheduling
13.3.5 Ground System DMGTS Post-Servicing Support
13.3.6 Ground System DMGTS De-orbit Support
13.4 Ground Segment Mission-Level Operations and Mission Planning Support
13.5 DM Simulators and DM Operations Training

14.0 Mission Operations

15.0 Spare Components

Each WBS element includes all labor, subcontracts, materials and other direct costs for that element. WBS elements are defined below.

1. **Project Management** — Manage the design, development, manufacturing and delivery of the de-orbit module for the life of the mission. Costs include any indirect costs and mission insurance as required by the contract.

    1.1. Resources Management — Monitor and assess resource allocations and utilization. May include the assessment of resource margins necessary to meet mission schedules. Resources include personnel, facilities, and material.

    1.2. Schedule Management — Develop, maintain and analyze start-to-finish program schedules to manage the design, development and production of the DM. The cost of long-range forecasting and planning for corrective actions is included.

    1.3. Configuration Management — Configuration control of drawings, specifications, documentation and hardware configurations. Include the cost of maintaining control boards, action item lists, and change request documentation.

    1.3.1 Document Management
    1.3.2 Photographic and Video Documentation

    1.4 Project Reviews — Includes all labor, subcontracts, materials and other direct costs to prepare, conduct and respond to request for actions associated with external reviews. These reviews may include the confirmation review, preliminary design review, specifications or systems requirements review, conceptual design review, pre-environmental and pre-ship review, and the two to four reviews associated with the launch activities.

    1.5. Travel — All travel in support of the project.

    1.6. Contract and Procurement Management — Managing and maintaining external contracts and subcontracts with venders, suppliers and team members. Include cost of performance measurements, progress tracking and status reporting. May include maintaining procurement processes that track delivery, inspection and stocking of parts and equipment

    1.7. Risk Management — Development of a Risk Management Plan and documentation, tracking of project risks, and developing plans to mitigate risk.

    Figure 1. HST Robotics Vehicle De-orbit Module Work Breakdown Structure

    1.8 Special Studies — Special analysis and trade-off studies during the course of effort as needed.

2. Systems Engineering — Design and development of systems architecture of the DM and the internal and external interfaces to the DM subsystems. Includes DM-level support to ensure the DM bus, Ejection Module, HST, payload(s), ground system(s)

and launch vehicle are integrated to support the mission. Includes the generation/ maintenance/ verification of technical requirements, allocations, budgets and analyses.

2.1. Systems Engineering Management — Manage engineering resources necessary to develop and complete the DM systems engineering functions. Include personnel management, coordination between subsystems and carrying out operational activities.

2.2. Systems Engineering Design — Design solution to meet the DM's mission requirements. Include working with the customer to understand the requirements, developing the operations concept, developing the architecture, identifying and managing the DM system and subsystem requirements, developing the ICDs, and defining the environments.

2.2.1 Understanding the Requirements
2.2.2 Operations Concept Development
2.2.3 Architecture Design and Development
2.2.4 Requirements Identification and Management
2.2.5 Interfaces and ICDs
2.2.6 Mission Environments

2.3. Systems Engineering Implementation — Engineer the system during the fabrication, testing, and operations. Includes validation and verification at the DM level and at the mission level. Included management of technical budgets/allocations such as mass, power, sensitivity to jitter, systematic errors, pointing and alignment errors and control system induced errors.

2.3.1 Validation and Verification
2.3.2 Technical Resources Budget Tracking
2.3.3 Technical Risk Management

3. **Electrical System** — Design, build, integrate and test the DM complete electrical system. Include test and verification with element interfaces.

3.1. Electronic Parts & Radiation Effects — Develop and implement a radiation effects analysis of all susceptible parts on the DM. May include analysis to determine mission exposure, parts testing, and alternative design development to remove a weak part.

3.2 Power System — Design, test, and analysis to include Energy Balance, Stability, Battery Cell Life, Solar Array, Power Bus Transient, Power Bus Distribution, and SA Life Test.

3.3. Command & Data Handling — Design, build, integrate and test the DM complete Command and Data Handling system. These costs may include development of simulations and models to support trade studies for on-board data reduction, processor computational loading, margin analysis and data storage and handling requirements.

3.4. Communications — Design, build, integrate and test the DM complete Communications system. These costs may include development of simulations and models to support trade studies for data transfer rates, and link margin analysis.

3.5. Electrical System Accommodations — Analysis the power, thermal, and environmental testing for the complete electrical system. May include development of simulations and models to support trade studies and margin analysis. May include power, data and software test beds along with prototype or mock-ups.

4. **Mechanical System** — Design, document, and build the various mechanical systems of the DM. May include mathematical modeling, stress analysis, subsystem proof tests, and analysis of loads induced by mission elements like the launch vehicle and transportation equipment.

5. **Thermal Control** — Design, analyze, document, and build the DM thermal control system. Includes active and passive elements of the thermal control system maybe included. Includes defining the operational temperature limits for the DM.

5.1. DM Module Thermal System Design Thermal Analysis — The DM thermal team shall thermally analyze the DM during design, fabrication, testing, and operations. Models shall be correlated to actual performance and audited for model errors. All baseline design models shall be documented. Models shall be able to predict both transient and orbit average temperatures of all spacecraft subsystem components during each phase of the mission to ensure that the thermal design maintains all components within acceptance limits. Trade studies shall be performed to optimize the overall design. Frequent interaction and reporting shall occur about the progress of thermal system design.

5.2 Thermal Components —All thermal components shall by flight qualified to meet the mission requirements, the SOW, and the DRD. DM thermal team shall be responsible for procuring, assembling, testing and documenting all thermal components, assemblies. Frequent interaction and reporting shall occur about the progress of thermal component procurement and assembly.

5.3 DM Thermal Interface Requirements — The DM thermal interfaces shall be documented thru, ICDs and a reduced model with a user's guide as stated in the SOW and the DRD. DM thermal systems shall work with the EM and HST thermal systems to ensure no potential thermal issue between the DM and the EM or HST prevents achieving the overall system requirements. Frequent interaction and reporting shall occur about the progress of working the thermal interface requirements with the EM and HST teams.

5.4 Design Verification — The DM system design shall be verified via thermal vacuum/thermal balance performance testing as stated in the SOW and the DRD. The DM component design shall be verified via thermal vacuum/thermal balance performance testing and/or qualification/life test units as applicable. Models shall be updated based on test results. Testing shall be documented.

5.5 Thermal Deliverables — Thermal deliverables shall be as stated in the SOW and DRD.

5.6 Thermal Model Criteria — Thermal model correlation criteria shall be per the SOW and the DRD. All flight telemetry points and component sensitive to thermal variations shall be predicted and correlated within their derived thermal sensitivity requirement.

5.7 Thermal Model Data Requirements — Thermal model data is per the SOW and DRD.

5.8 DM Module Thermal Testing —The DM shall be tested per GEVS and be fully 1-g testable. Thermal testing is required as stated in SOW and DRD.

6. **Guidance, Navigation, and Control (GN&C)** — Design, build, integrate and test the DM's complete guidance, navigation and control system. Includes test and verification with mission element interfaces. May include developing fault detection and correction hardware logic at the subsystem or box level.

6.1 GN&C Systems Engineering — Design, build, integrate, test, and analyze the elements of the DM's GN&C system. Specify performance for EM translational and attitude actuation systems. Includes integration of GN&C system with other major subsystems including HRV GA and EM GN&C. Includes test and verification of GN&C at a subsystem level including GN&C subsystem trades and participation in system level trades.

6.2 Attitude Determination and Control System (ADCS) — Design, build, integrate, test, and analyze the elements of the DM's Attitude Determination and Control System. Includes test and verification with other GN&C element interfaces as well as HRV GA and docking interface and development of hardware/software interface tests at the subsystem or box level. May include performance and interaction tests, analytical model development, trade studies, and design optimization.

6.3 Trajectory Design — Design the mission trajectory based on the HRV and DM specified performance. Includes development of DM fuel budget. May include analytic model development and testing.

6.4 Absolute Orbit Determination — Design, build, integrate, and test all elements of the Orbit Determination system for estimation of DM's position, velocity, and other parameters. Includes test and verification with other GN&C element interfaces and development of hardware/software interface tests at the subsystem or box level. May include performance and interaction tests, analytical model development, trade studies, and design optimization.

6.5 Propulsion — Design, build, integrate and test the spacecraft's propulsion system. These costs should include test and verification with mission element interfaces. May include analytical model development and testing as well as costs for performing trade studies and design optimization.

6.6 Relative Navigation and Control System Design, build, integrate, test, and analyze the elements of the Relative Navigation and Control System. Includes test and verification with other GN&C element interfaces as well as HRV GA and docking interface and development of hardware/software interface tests at the subsystem or box level. May include performance and interaction tests, analytical model development, trade studies, and design optimization.

7. Flight Software — Provide end-to-end leadership of all flight software development activities associated with the de-orbit module (some flight software may reside in Ejection Module). Focus is on end-to-end processes, flight operations concepts, flight architectures, software requirements, ground and instrument interfaces, test beds and tools, test and validation, I&T support, launch readiness and on-orbit maintenance preparations. Includes fault detection and correction software logic at the subsystem or box level.

7.1 Flight Software Element – Real-time, embedded software and firmware residing in the DM (and possibly the EM) responsible for functions such as the operating system, time management, spacecraft subsystem command and control, and telemetry monitoring and downlink.

7.1.1 Planning and Requirements Life Cycle Activities – Finalize the planning. Develop and document the requirements according to HST Program approved software development processes.

7.1.2 Design Life Cycle Activities – Design and document the Flight software according to internal and external requirements according to HST Program approved software development processes.

7.1.3 Implementation and Delivery Life Cycle Activities – Create, document, and test the code and data that meets requirements according to HST Program approved software development processes. Develop and deliver training materials. Deliver subsystem software models and documentation. Deliver Flight software releases to customers such as I&T.

7.1.4 Pre-Launch Sustaining Engineering through De-orbit Activities – Provide sustaining engineering through launch, and maintenance through de-orbit activities.

7.1.5 Software V&V – Provide organizationally independent Flight software verification and validation.

7.2 Software Development and Validation (SDV) Software Element – A combination of commercial and developed software residing in workstations and in a high fidelity simulation facility that hosts the creation and testing of the Flight software and includes spacecraft subsystem software models.

7.2.1 Planning and Requirements Life Cycle Activities – Finalize the planning. Develop and document the requirements according to HST Program approved software development processes.

7.2.2 Design Life Cycle Activities – Design and document the SDV software according to internal and external requirements according to HST Program approved software development processes.

7.2.3 Implementation and Delivery Life Cycle Activities – Create, document, and test the code and data (combination of commercial and developed) that meets requirements according to HST Program approved software development processes. Develop and deliver training materials. Deliver SDV software releases to the deliverable simulator facilities (SDVF and two copies).

7.2.4 Pre-Launch Sustaining Engineering through De-orbit Activities – Provide sustaining engineering through launch, and maintenance through de-orbit activities.

7.2.5 Software V&V – Provide organizationally independent SDV software verification and validation.

7.3 Software Management – Manage the development and V&V of the software elements to include resource and schedule management, configuration and risk management, interpretation of software measures (metrics), and software reviews.

7.4 Government Insight and Support of Government FSW Development – Provide consultation and access to existing materials to support HST Program and NASA IV&V insight. Provide minimal assistance, if requested, to government personnel developing EM Flight software.

7.4.1 NASA IV&V Support – Provide documentation and information as requested to close out issues submitted by NASA IV&V.

7.4.2 HRSDM Project EM FSW Development and V&V Support - HRSDM EM Flight Software Development and V&V Support – Provide support for such things as anomaly resolution as requested by the HST Program for any government-developed and validated EM Flight software.

7.5 Software Maintenance - Provide configuration management and maintenance of the Flight software and its applicable SDV software through its de-orbit. Prepare new Flight software uploads and patches using the same HST Program approved software development processes as the original code and data.

7.6 Software Development, Validation, and Maintenance Environment - Document and deliver any environment products (e.g., COTS software) not already included in the SDV software element delivery.

7.7 Software Development and Validation Facility (SDVF) - Design, develop, certify, document, and deliver the SDVF simulation facility hardware, and two copies. The facility includes flight-like avionics hardware.

8. Integration, Test & Verification — Document, integrate and test the DM. May include subsystem integration, interface testing, development of Safe-To-Mate procedures, operational procedures, and development of operational techniques. May include verifying that DM level requirements are met.

8.1. System Assembly and Integration — Document and integrate each of the subsystems onto the mechanical bus structure. May include developing liveness tests, system level functional tests, and comprehensive performance tests.

8.2. System Test — Design, analyze, document and implement environmental tests on the DM. May include test facilities, supplies, consumables and personnel resources. May include development of system interaction tests.

8.3 Mission-Level I&T— Support the overall HRSDM Integration and Test phase that is expected to take place at the NASA Goddard Space Flight Center.

8.3.1 DM to EM and HST Interface Tests — Provide sustaining engineering support for the DM to EM integration and testing, and the HRV to HST Integration and Testing.

8.3.2 DM Simulators — Design, development, integration, and test of the various DM simulators.

9. Mission Assurance — Implement the requirements of the mission's performance assurance plan on the DM. May include parts evaluation, screening, upgrading or redesign.

10. **Launch Support** — Define, document, and test the interfaces between the launch vehicle and the DM. May include process and procedure development, integrated procedures and integrated testing.

11. **HST Interface**

    11.1 HST Battery Augmentation — Design, development, integration, and test of the system used to augment the Hubble Space Telescope operational battery capacity.

    11.2 HST Gyro Augmentation Support — Design, development, integration and test of the Hubble Space Telescope Gyro Augmentation capability including communications capabilities between the DM and HST.

    11.3 HST Mechanical Interface — Design, development, integration, and test of the Hubble Space Telescope mechanical interface.

12. **Ejection Module Interface** — Design, development, integration, and test of the Ejection Module interface.

13. **De-orbit Module Ground System Development** — Design, development, integration, test, and operation of the ground system used to control the DM.

    13.1 Ground Segment and Operations Management— Provide the technical and management oversight of all of its ground segment and operations development support activities.

    13.2 Ground Segment and Operations Systems Engineering — Perform the systems engineering tasks required to coordinate and integrate HRVand ground segment development and ensure compatible end-to-end system design. Also support the HST Program's development of the HRSDM operational concept and provide necessary operational procedures and documentation.

    13.3 Ground System Hardware and Software — Support the HRSDM team in integrating the DM with the HRV ground system and provide the DMGTS that will process all data types and formats that the DM will transmit and receive during all phases of the mission.

    13.3.1 Ground System DMGTS — Provide a DMTGS that provides the hardware and software necessary to command the DM/EM and monitor DM/EM telemetry. The DMGTS shall be able to receive and process all data types and formats that the DM will transmit during all phases of the mission

    13.3.2 Ground Segment Trade Studies — Support the HST Program in conducting top-level systems analyses and trade studies pertaining to the ground segment and mission operations. These studies will assess if the DMGTS should be built from a CCS test system or a contractor provided base system.

13.3.3 Ground System DMGTS Network and Security — Assess their ground system to ensure network security compliance with NPG 2810.

13.3.4 Ground System TDRSS Scheduling — Provide the requirements that will be needed to add the scheduling of TDRSS forward and return links to the HST scheduling system to support DM direct operations.

13.3.5 Ground System DMGTS Post-Servicing Support — Provide support and training at GSFC to the HST Program for maintaining and upgrading the DMGTS.

13.3.6 Ground System DMGTS De-orbit Support — Verify the integrity of the DMGTS prior to the de-orbit phase and, if needed, restore the system to an as-delivered state.

13.4 Ground Segment Mission-Level Operations and Mission Planning Support — Support the HST Program in the development of nominal and contingency operational to include the review of procedures for completeness and safety, testing, database certification, and the training of operational personnel on their use.

13.5 DM Simulators and DM Operations Training — Train HRV team personnel in the operation and maintenance of the contractor supplied simulators and also train HRSDM team personnel in the operation and maintenance of these simulators, and provide operations-oriented training.

14. Mission Operations — Support all operational phases of the HRSDM and develop a flight procedures handbook to document nominal and contingency procedures.

15. Spare Components — For common components to be used in Ejection Module (EM).

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Attachment G

FINANCIAL REPORTING REQUIREMENTS

Hubble Space Telescope (HST)

HST Robotic Vehicle (HRV)

De-orbit Module (DM)

June 1, 2004

Goddard Space Flight Center
Greenbelt, Maryland

FINANCIAL MANAGEMENT REPORTING REQUIREMENTS

General

Financial Management Reports shall be submitted by the Contractor on the NASA 533 series reports, in accordance with the instructions on the reverse of the forms, NASA Procedures and Guidelines NPG 9501.2D entitled "NASA Contractor Financial Management Reporting" dated May 2001, and additional instructions issued by the Contracting Officer.

a. Level of Detail

The reporting structure shall report all costs at level three of the Work Breakdown Structure (for example 1.1 "Contract Management") with summaries for each higher level (for example 1 "Project Management" and total program), Attachment F of Section J of this contract. The reports shall contain a breakdown of each element of cost, i.e., direct labor hours/dollars, Subcontracts, Other Direct Cost, G&A, etc. The contractor shall provide the same report for all subcontracts in excess of $15M. **As stated in NPR 9501.2D, NASA strongly encourages electronic contractor cost reporting. The preferred formats are Excel and Adobe.**

b. Distribution

The Contractor shall distribute 533 reports to each addressee indicated in the Contract Clause G.2, FINANCIAL MANAGEMENT REPORTING. These reports shall be distributed not later than the fifteenth (15th) calendar day following the month being reported.

c. Reporting Requirements

Each report sheet shall provide costs data for reporting categories presented below:

1. Direct Labor Hours
   - On-Site
   - Off-Site

2. Direct Labor Workyears
   - On-Site
   - Off-Site

3. Direct Labor Cost (Calculated based on Direct Labor Hours)

   - On-Site
   - Off-Site

4. Fringe Benefit Costs

5. Overhead

On-Site
Off-Site

6. Other Direct Costs
   Materials
   Local Travel
   Non-Local Travel
   Subcontracts
   Other (Specify)

7. Material Handling Overhead

8. G&A Expense

9. Cost of Money (if proposed)

10. Fee

    Award Fee
    Performance Incentive Fee

11. Total CPAF/PIF

NNG05EA01C
Attachment J

Safety and Health Plan

Hubble Space Telescope (HST)

HST Robotic Vehicle (HRV)

De-orbit Module (DM)

July 10,2004

Goddard Space Flight Center
Greenbelt, Maryland

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APPENDIX E SPACE EXPLORATION SYSTEMS ENVIRONMENT, SAFETY & HEALTH PLAN

1 OVERVIEW

Lockheed Martin is committed to mission success and dedicated to satisfying customers by delivering high quality products and services. Providing a safe workplace and protecting the environment are essential elements of achieving mission success. Lockheed Martin Environment, Safety and Health (ESH) and Program System Safety provide a comprehensive system for hazard identification and control throughout the program life cycle. The combined ESH and System Safety programs increase customer value by integrating ESH and System Safety in all phases of the contract, from design through test, production, and deployment; thus, providing an efficient mechanism for early identification and mitigation of risk to personnel, environment, and product.

Lockheed Martin Space Exploration Systems (SES) in Denver operates within the Lockheed Martin ESH Management System (MS) to ensure personnel safety and protection of the environment. This management system implements the ESH program and is in compliance with federal, state, and local requirements. The ESH MS consists of hazard identification, implementation of mitigating controls, vigilant assessment, and continuous improvement. Employee communication, training, management reviews, and a rigorous root cause determination and corrective action process focus on mitigating risks and preventing injuries. Additionally, the management system provides for compliance with contractual requirements; thus, it will ensure compliance with NPR 8715.3, NASA Safety Manual.

This Safety and Health plan summarizes how Lockheed Martin ensures the safety and health of its personnel in accordance with the Lockheed Martin Corporation Environment, Safety and Health Policy; Space Systems Company Environment, Safety and Health Policy; and the ESH MS. Past performance and accident history are summarized in Attachment 1.

Changes to this plan are subject to approval by the Contracting Officer(s) of the customer(s) to whom the changes affect. The approved Safety and Health Plan will be included in the applicable contracts.

1.1 Policy

The Corporate Policy CPS-015, Environment, Safety and Health states: "Lockheed Martin Corporation is committed to conducting its operations in a manner that prevents accidents and environmental, safety, and health incidents; ensures the safety of employees, contractors, and the public; protects the environment; and conserves natural resources." Accordingly, Lockheed Martin will:

- Institute ESH management systems that minimize risk, ensure ongoing compliance with applicable laws and regulations, and promote continual improvements of ESH performance and management systems
- Integrate ESH considerations into business operations, including but not limited to: product design, services, procurement, manufacturing, joint ventures, property renovation/ rearrangement, and business and property acquisitions, consolidations and divestitures

- Share ESH best practices and lessons learned among Lockheed Martin business units and entities
- Ensure employees are aware of ESH responsibilities in their jobs and encourage every employee to take responsibility for ESH performance
- Respond to employee, community, customer and regulatory agency concerns regarding potential ESH impact from Lockheed Martin operations, as appropriate
- Participate in public policy processes to promote the development of ESH laws and regulations that are protective of human health and the environment, and are consistent with sound science and risk assessment principles.

The Lockheed Martin Policy 1.7.8, Environment, Safety and Health states: "It is the policy of Lockheed Martin Space Systems Company to conduct its business activities and operations in a manner that:

- Protects public and personnel safety and health
- Protects the environment
- Minimizes risk to the company
- Develops safe and environmentally sound products for its customers
- Prevents damage to products, protects facilities and resources from losses
- Complies fully with applicable federal, state and local environmental, safety and health laws
- Pursues continual performance improvement
- Integrates Environment, Safety, and Health (ESH) considerations into business operations and processes.

Line management is responsible for compliance of the operations under their control and for the safety and health of their employees."

Both policies are consistent with the safety objectives of OSHA and NASA. This Safety and Health Plan describes the method of compliance to NASA Safety Manual NPR 8715.3 requirements applicable to Lockheed Martin SES products. The Lockheed Martin command media described herein provides specific direction to employees for the implementation of the Lockheed Martin Corporation and Space Systems Company ESH policies. This Safety and Health Plan provides an overview of the Lockheed Martin policies, practices and procedures as they relate to ESH.

1.2 Goals and Objectives

The goal of Lockheed Martin ESH is to be the model of excellence in environmental stewardship and workplace safety and health. Lockheed Martin is supporting the recently launched Corporate initiative of Target Zero that sets a goal of reaching zero injuries. To work toward the zero injury goal, Lockheed Martin set a target of reducing the day away cases rate from 0.31 in 2003 to 0.20 in 2008 and reducing the recordable cases rate from 1.66 in 2003 to 1.25 in 2008.

The objectives of Lockheed Martin's ESH program are to develop strategies, programs, and provide services that enable the company to cost-effectively achieve regulatory compliance and mission success. In partnership with our customers, Lockheed Martin integrates environmental, safety and health programs with business processes. Essential program philosophies include:

- Evaluation of ESH programs using the ESH Management System at least annually. This includes the review of requirements, objectives, policies, and procedures to ensure the meeting of goals.
- Provide a safe and healthful workplace and maintain facilities in such a manner that satisfies regulatory requirements.
- Review and evaluate new or modified equipment, processes, procedures, and substances for safety prior to operation. Ensure that all applicable safety and health standards are being fully met and that the process is safe.
- Perform operations in a manner that protects the environment.
- Comply with federal, state, local, corporate, and customer requirements.
- Provide safety education, qualification/certification, and training programs consistent with applicable laws and regulations.
- Periodically review programs for compliance with regulatory requirements.
- Report and investigate injuries, illnesses, and accidents, and significant near-misses pertaining to personnel safety in the workplace, without retribution to the employees, with emphasis on understanding the root-cause that allowed the unwanted sequence of events to occur. Implement corrective action to prevent occurrence.

The annual evaluation and status of the ESH program begins with an ESH risk assessment. ESH programs listed as high risk for non-compliance drive the development of objectives to improve those programs. This dynamic process ensures compliance with new or revised regulations. Refer to Section 1.8 for a more detailed description of the Lockheed Martin ESH Management System, which depicts how the Lockheed Martin ESH program implements performance criteria of the Performance Evaluation Profile (PEP).

1.3 Management Leadership

Managers and supervisors have the primary responsibility for maintaining a safe and healthful workplace for their employees and for ensuring their operations are conducted in a manner that protects the environment. Program personnel are supported toward safety excellence by Dr. Vance Coffman, CEO of Lockheed Martin Corporation, as indicated by his leadership in Target Zero. Target Zero is the Corporation's initiative to minimize accidents and injuries across the Corporation. Mr. Tom Marsh, President of Lockheed Martin Space Systems Company, has demonstrated his commitment to Target Zero by stating, "*I expect everyone to work safely and look out for the well-being of their fellow employees. A zero injuries mindset is absolutely essential to Mission Success, and for Space Systems, it is an operational imperative*."

Mr. Aubrey Pharo, Lockheed Martin—Denver Operations, Manager of Environment, Safety & Health, is the point of contact for implementation of Target Zero for Lockheed Martin—Denver Operations. In working toward the goal of zero injuries, Mr. Pharo has increased local ESH resources with an emphasis on creating greater awareness of personnel safety in the workplace.

Mr. Steve Keppers, Program Manager, states "*As program manager I am personally responsible for the whole program and safety is a key program driver for ensuring both the protection of the public/personnel, and protection of all assets associated with the program, including the environment. This theme, as captured in this plan, will be a foundation to our program.*"

Fig. 1.3-1 Lockheed Martin ESH Management Structure

The management structure to assure that requirements are communicated, understood, and implemented across Lockheed Martin, and specifically on the SES program, is depicted in Fig. 1.3-1.

ESH requirements are documented in a hierarchical command media structure for flow-down of regulatory requirements and management directives, and to distribute requirements to Lockheed Martin line and staff organizations and employees. These hierarchies are:

- Lockheed Martin Policies (Directives)
  - Documents that describe values, principles, objectives, and requirements for conducting company business. These documents are usually brief statements that avoid detailed implementation instructions and assign responsibilities to specific organizations or to members of management.
- Lockheed Martin Procedures (Processes)
  - Documents that describe system level processes or responsibilities involving two or more organizations. These documents generally define management systems, subsystems or work processes, and use flow charts, when appropriate, to supplement the written description.
- Lockheed Martin Practices (Standards)
  - Documents that describe working level processes and/or responsibilities and give more detailed instructions than procedures.

The primary SES applicable internal implementing documents for ESH management at Lockheed Martin are listed in Attachment 2. The most current version of these documents, or their replacement documents, will be used for work performed under this contract.

In addition to Lockheed Martin command media, there are a number of provisions that are applicable to Lockheed Martin SES subcontract actions relative to employees. Included in subcontracts are provision 52.222-4, Contractor Work Hours and Safety Standard Act—Overtime Compensation, and NASA FAR 1852.223-70, Safety and Health. These and other SES applicable government documents are listed in Attachment 3.

1.4 Employee Involvement

Employees are expected and encouraged to ensure safe conduct of all activities in the workplace. Employees have, with no fear of reprisal, the freedom and authority to report any unsafe condition and to suspend operations until the unsafe condition is mitigated. Refer to Section 2.3 for more detailed information regarding employee reporting of hazards.

All employees are responsible for the following:

- Complying with Lockheed Martin command media
- Adhering to Lockheed Martin values of ethics, excellence, "can do," integrity, people, teamwork, and civic pride
- Performing at all times, in a manner to ensure maximum safety to self, fellow workers, the public, and the environment; and to minimize property loss or damage
- Accepting and demonstrating responsibility for their own and others' safety by not attempting work that they do not feel qualified for or physically able to perform
- Maintaining current safety and health training certifications
- Performing assigned work according to ESH requirements
- Obtaining specific instructions and/or clarifications from the supervisor, manager, or ESH organization before proceeding with assigned work in situations where an ESH requirement or procedure is not completely understood
- Observing and adhering to all warning signs, signals, and notices
- Promptly reporting hazards observed
- Immediately reporting work-related injuries, illnesses, and mishaps/near misses including actual or suspected hardware damage, exposures, or unapproved environmental releases
- Understanding emergency response, notification, and evacuation procedures; hazardous materials and chemicals requirements; and safety risks of operations in area of responsibility; and
- Identifying areas in which safety can be improved.

1.5 Assignment of Responsibility

1.5.1 Lockheed Martin Corporate

Dr. Vance Coffman, CEO Lockheed Martin Corporation, is the leader to establish commitment to high safety performance in the Corporation. He has demonstrated this commitment through the Target Zero injuries goal program. In a February 25, 2004 letter from Dr. Coffman and CFO Mr. Stevens, it states, "*Lockheed Martin is setting a new long-term safety objective: to create a workplace where there are no injuries and all employees develop and maintain a 'zero accidents' mentality.*"

Mr. Ken Meashey, Director of Corporate Energy, Environment, Safety and Health (CEESH) manages emerging federal and state issues concerning environmental protection, safety, and health in concert with Lockheed Martin's ESH policy. CEESH maintains an intranet homepage that provides resources to all Lockheed Martin locations.

1.5.2 Lockheed Martin President and Vice President Staff

Mr. Tom Marsh, Lockheed Martin President, is responsible to champion Lockheed Martin Corporate safety objectives. Mr. Marsh demonstrates his support of safe operations by committing programs and resources to ensure safe conduct in the workplace. Examples include his support of Corporate's Target Zero initiative, his establishment of human error prevention training for all operational employees, and his endorsement of the Error Prevention Council that is dedicated to process improvement. Mr. Marsh's staff ensures implementation of his directives in their functional areas of the company. Specific responsibilities include:

- Providing leadership and stewardship for compliance to Lockheed Martin ESH programs including compliance to federal, state, local, customer, and corporate requirements.
- Ensuring adequate resources to implement the ESH programs to minimize risks to personnel, environment, Lockheed Martin customers, contractors, and the public.

1.5.3 Lockheed Martin ESH Management

The Lockheed Martin ESH program is administered by the Lockheed Martin ESH Director, Mr. Mark Posson. Mr. Posson is responsible for:

- Directing, guiding, and coordinating the development and implementation of the ESH MS, as well as common processes, procedures, and standards
- Standardizing and integrating ESH programs across Lockheed Martin business units to the greatest extent practical
- Ensuring continual improvement of the ESH MS, programs, and performance
- Ensuring Lockheed Martin ESH management reviews are conducted, and the Policy/Directive and Procedure/Process is updated as appropriate
- Representing Lockheed Martin with Corporate Energy, Environment, Safety & Health, and serving as the central point of contact for Lockheed Martin.

Mr. Aubrey Pharo, Lockheed Martin—Denver Operations ESH Manager, is responsible for the following:

- Developing programs, procedures, practices, and standards to implement the Lockheed Martin ESH MS. To the extent practical, the common Lockheed Martin process and standards shall be utilized
- Ensuring integration of ESH requirements into operations and processes
- Continually improving ESH process and standards
- Developing and maintaining performance measurements consistent with the ESH MS
- Providing overall planning and direction for the Lockheed Martin—Denver Operations ESH program
- Reviewing and interpreting federal, state, and local ESH laws and regulations and developing and disseminating ESH requirements.

1.5.4 Program Managers

Program managers are responsible for the following:

- Selecting and integrating applicable ESH requirements, standards, and programs into operations and processes throughout the program life cycle, including supporting verification and validation
- Providing a safe and healthful workplace for personnel, preventing environmental pollution in their operations, and ensuring safe and environmentally sound products and services for customers
- Conducting operations in compliance with applicable laws, regulations, standards, command media, and customer requirements
- Fostering a culture that encourages personnel to take responsibility for ESH performance
- Seeking opportunities to implement and share Lockheed Martin and industry best ESH practices
- Complying with and advising employees of ESH regulations, policies, programs, processes and standards that pertain to their operations
- Investigating mishaps and near misses, identifying root causes and ensuring implementation of corrective actions
- Identifying and implementing corrective actions to mitigate risks to personnel and hardware
- Verifying personnel training is current and appropriate for work performed
- Recognizing and rewarding exemplary safety behaviors and administering coaching, counseling, and disciplinary actions, where appropriate, when employees have not adhered to Lockheed Martin and customer ESH requirements.

1.5.5 ESH Engineers

Lockheed Martin—Denver Operations ESH Engineers report to Mr. Aubrey Pharo and are responsible for implementation of the SSC ESH Management System, including:

- Developing and implementing personnel safety and environmental management programs
- Establishing ESH criteria and requirements applicable to design, manufacture, assembly, test, servicing, maintenance, and transportation of flight and ground systems, and supporting equipment, tooling, and facilities
- Ensuring compliance with established ESH requirements by means of formal reviews and assessments
- Performing reviews of manufacturing process instructions and test and operating procedures, including those required for handling and transportation of flight or major test articles
- Monitoring work areas and activities to identify potential hazards, performing hazard assessments, and verifying adherence to safety requirements
- Apprising management of personnel safety performance
- Overseeing procurement, storage, use, and disposal of hazardous and other ESH related materials and items
- Developing and disseminating safety data for awareness, training, use, and benefit of other personnel at all organizational levels
- Ensuring that environmental management risks are properly managed and operations are conducted in compliance with applicable regulations.

Program System Safety Engineers complement the ESH function in the conduct of operations through hazard analysis of program unique hazards. Hazard controls are implemented via the program design features or procedures. Program System Safety personnel are responsible for protection of flight hardware and related tasks including risk assessments, hazard analyses, and mishap and incident investigations and reporting.

1.5.6 Program ESH Officer (Designated Safety Official)

The Program Safety Officer (PSO) is the designated safety official for interfacing with the NASA customer on ESH projects and issues. The Safety and Health Plan is implemented by the PSO with assistance from department managers, line managers, supervisors, and other personnel responsible for implementing the elements of the Plan. The PSO provides a focal point for OSHA reporting, regulatory matters, and serves as the point of contact with the Center Safety Office. The PSO also participates in meetings and other activities related to the customer's ESH program.

1.5.7 Company Physician

The Lockheed Martin—Denver Operations physician information is as follows:

Name: Dr. Edwin Healey

Address: Mail Stop 1398, 12257 S. Wadsworth Blvd., Littleton, CO 80125

Phone: 303-977-4676

The PSO is the local point of contact to NASA clinics during operations to facilitate the communication of medical data, although actual correspondence of employee medical data must be directly communicated to or from the Lockheed Martin physician.

1.5.8 Building Fire Warden

Lockheed Martin—Denver Operations Plant Protection is directed by Chief Darrell Root and, along with his staff of over 70, serves as the authority having jurisdiction for the Waterton campus and provides fire warden duties for Lockheed Martin. The PSO is the point of contact for communicating and coordinating with Plant Protection the emergency planning and response for the program. The response includes implementation of evacuation procedures in the event of fire, bomb threat, dense smoke, toxic fumes, gas leak, or any condition that imposes a safety threat to personnel, systems, or the facility. Consistent with individual employee responsibility for safety, any employee is authorized to conduct emergency response within the limits of their training while ensuring their own safety. Lockheed Martin emergency response procedures are in place to manage such events at Lockheed Martin facilities.

1.6 Provision of Authority

The Lockheed Martin ESH MS requires that standards are maintained current with applicable federal, state, and local regulations and contractual requirements. This is accomplished by periodically reviewing, and updating as necessary, ESH command media documents that control work and products. These controlling documents are accessed through a web-based intranet that is updated when document revisions are released. Updates to command media are subject to a review and approval process independent of the Lockheed Martin ESH manager to ensure checks and balances. This web-based command media system provides for updated documentation throughout the life of the contract.

1.7 Accountability

Management and employees are accountable for implementation of safe practices and safety programs that adhere to command media and are responsive to requirements of regulatory agencies and customers. To ensure management accountability, ESH provides senior management a not-to-exceed target rate for injuries. Safety performance for Lockheed Martin lines of business is presented to senior management along with summary incident reports and related corrective actions. Senior management is measured on performance to their target.

Employee training is tracked on individual training plans. Employees have access to their training plan and training status via the Lockheed Martin intranet. Training includes compliance training, applicable to all or large segments of personnel, and skills certification training that is required based on specific tasks assigned to employees. Employees and supervision are responsible to ensure training is kept current.

1.8 Program Evaluation

The Lockheed Martin ESH MS provides a methodical, uniform, and consistent approach to risk identification, assessment and management, and complements ESH policies and site-specific processes. After assessing risks and understanding compliance requirements, business units develop a set of business objectives to set measurable targets. The ESH MS addresses the following management system/process needs:

- Identification of requirements
- Assessment of applicability of requirements
- Assessment of risks
- Establishment and maintenance of command media to describe actions that are to be taken to ensure requirements are met
- Performance to command media and agency/legal requirements
- Assessment of performance
- Establishment of goals
- Assessment of the management system
- Revision of the management system based on lessons learned from any of the above.

The business unit self-assesses its performance and takes corrective actions, prompting the cycle to begin again. The ESH MS conforms to ISO 14001, CPS-015, and Functional Procedure ESH-01. The following elemental sections provide an overview of the ESH MS (refer to Fig. 1.8-1 for a diagram of the ESH MS).

Figure 1.8-1 illustrates the management system core elements, the order of implementation and the relationship between the respective components. The intent of this chart is to provide a framework to implement ESH programs in a consistent and uniform manner.

Element 1—Identification and Review of Applicable ESH Elements and Requirements

The intent of this element is to provide a uniform and consistent approach to ensure ESH programs, including Emergency Response Plans, are current with applicable legal and other requirements.

- Lockheed Martin ESH reviews information sources to identify new or modified regulatory, contractual, and other requirements to determine site applicability. When it is determined that existing systems are not adequate, the appropriate control(s) to ensure compliance or conformance with requirements will be developed and implemented.

Element 2—Risk Assessment Review

The intent of the risk assessment process is to identify, assess, prioritize, and mitigate risks to the public, personnel, and the environment. The risk assessment will be performed in accordance with the ESH MS. In general, the risk assessment identifies and characterizes ESH hazards for developing general risk mitigation strategies. The intent is to determine which hazards are most significant and require management attention and to also identify actions that can be taken to reduce the potential risk associated with the identified hazards. The methodology considers both traditional ESH impacts (e.g. potential for injury and illness, degradation of environmental quality) and business impacts associated with ESH hazards (e.g., changing regulations, audits, customer requirements).

Element 2.5—Management System Review

The management system review assesses the effectiveness of the management system implementation and identifies opportunities for improvement. The review is to be conducted annually.

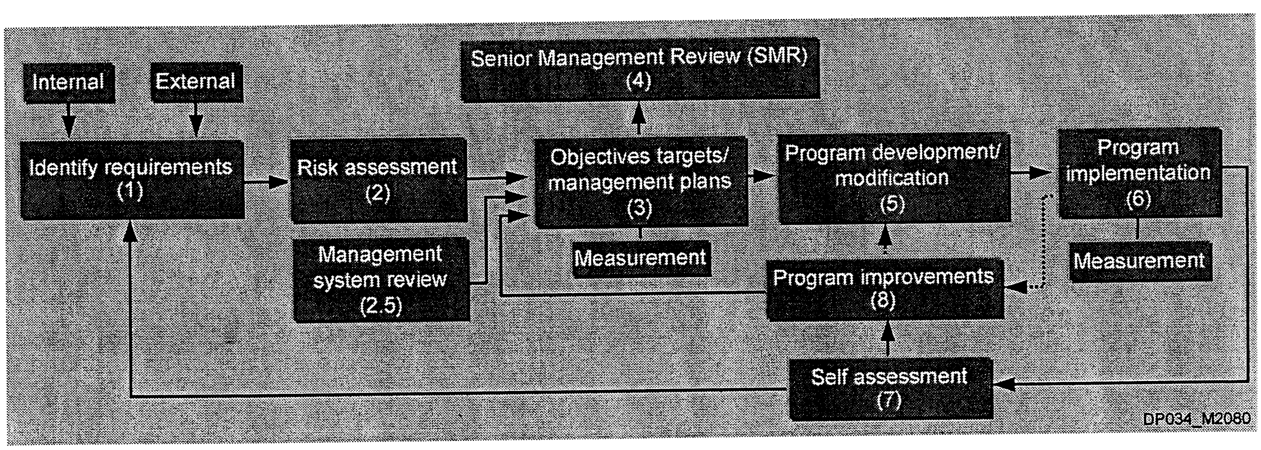

Fig. 1.8-1 ESH Management Flow Diagram

Element 3.0—Objectives, Targets and Management Plans

This element identifies how objectives and targets are used to correct a deficiency or enhance a process. Responsibilities, schedules, and resources are identified and updated, as appropriate.

Element 4.0—Senior Management Review

The Senior Management Review is performed annually and provides management with information on ESH performance, improvement plans, and other information necessary to integrate ESH considerations into the unit's business plan. The review includes the assessment of the ESH MS performance, objectives, targets, and progress on the continual improvement process.

Element 5.0—Program Development/Implementation Process

This element describes the process for design or modification of ESH programs, which will be used for program-specific development, implementation, and maintaining currency with both regulatory and customer requirements.

Element 6.0—Program Implementation

This element describes the process used for ESH program implementation, taking into consideration organizational structure, responsibilities, and delivery methods. Program performance shall be measured and the program shall be modified as necessary to ensure continual improvement.

Element 7.0—Self Assessment

This element describes the assessment process used to assess the effectiveness of the ESH MS, evaluate progress in meeting objectives, and to assess regulatory compliance. The self-assessment program identifies frequency, sites, and operations to be assessed.

Element 8.0—Program Improvements

This element focuses on the enhancement of the entire management system that can be identified through the self-assessment process, program implementation experience, and performance metrics. Improvements can include modification of existing, or development of new, programs. Major program improvements may be established as ESH objectives, while minor improvements may be handled through the corrective action process or other appropriate means.

Figure 1.8-2 depicts how Lockheed Martin's Safety and Health Plan implements the elements outlined in the PEP and can be used as performance criteria for program evaluation. The six elements to be scored in the PEP are listed along with the corresponding Lockheed Martin Safety and Health Plan section(s).

1.9 Documentation of Performance

The following list includes, but is not limited to, statistics, reports, and checklists used by Lockheed Martin to describe its approach to documenting safety and health performance:

- OSHA Recordable Injury or Illness
- Injury and Illness Incidence Rates to include day away cases, recordable cases, and severity
- Accident/Incident Investigation completed in accordance with the Lockheed Martin Supervisor's Incident Investigation (LMSII) process
- Safety inspections of work areas

For Lockheed Martin activities conducted on NASA property, statistics, reports, and checklists generated will be made available to NASA, upon request. In addition, Lockheed Martin acknowledges the following as standing requests of the government to be handled as described below for activities performed onsite at NASA Centers.

- Roster of Terminated Employees at NASA Centers—Lockheed Martin employees terminated following a permanent assignment at a NASA Center will be identified and reported to the Center Occupational Health Program Office. The report will be sent to the Occupational Health Officer no later than 30 days after the end of each contract year or at the end of the contract, whichever is applicable. Due to the temporary nature of SES activity at NASA Centers, no permanently assigned personnel are anticipated.
  - Information required:
    1. Date of report, contractor identity, and contract number
    2. Employee name, social security number, assigned Center badge number, and date of

Performance Evaluation Profile Element	SH Plan Section/Reference Document
1. Management Leadership and Employee Participation	
Visible Management Leadership	1.1, 1.5.1-1.5.6
Employee Participation	1.1, 1.4, 1.5.7-1.5.9, 2.1, 2.3
Implementation	1.5.3-1.5.7, 1.6, 1.7, 1.8
Contractor Safety	HR 10.11 Contractor Safety Program
2. Workplace Analysis	
Survey and Hazard Analysis	2.0, 2.1
Inspection	2.1, 2.2
Reporting	1.3, 2.2, 2.3
3. Accident and Record Analysis	
Investigation of Accidents and Near Miss Incidents	3.1, 3.1.1, 3.1.2, 3.1.3
Data Analysis	1.9, 3.2
4. Hazard Prevention and Control	
Hazard Control	4.1, 4.1.3
Maintenance	4.2, 4.3
Medical Program	1.5.8, 4.4
5. Emergency Response	
Emergency preparedness	5.0
First Aid	4.4
6. Safety and Health Training	6.0

Fig. 1.8-2 PEP Elements Matrix

termination

3. Name, address, and telephone number of contractor representative to be contracted for questions or other information.

- Material Safety Data. For hazardous materials identified under Federal Standard 313 and brought onto NASA property or included in products delivered to NASA, a Material Safety Data Sheet (MSDS) meeting the requirements of 29 CFR 1010.1200(g) will be provided, along with Federal Standard 313 information, as applicable. A single copy of each MSDS will be sent with the shipment of the material for use on NASA property. The MSDS may be retrieved by the Center's Shipping and Receiving and forwarded to the Center's Central Repository, along with new or changed locations and/or quantities normally stored or used. Refer to Attachment 4 for MSDSs of the currently known hazardous materials to be brought onto government property. Updated information will be provided to the customer when hazardous materials are brought onto government property or delivered to the government.

- Material Inventory. Each Lockheed Martin location on NASA property will compile an inventory of hazardous materials used at that location. The inventory shall include the following:

  1. Identity of the material
  2. Location of the material by building and room
  3. Quantity of each material normally kept at each location

MSDSs for hazardous materials used by Lockheed Martin are maintained in a database on the Lockheed Martin intranet. This intranet is an alternative to paper copies for employee access to MSDSs.

1.10 Government Access to Safety and Health Program Documentation

Lockheed Martin SES safety and health documentation for activities performed on government facilities shall be available for inspection or audit at the government's request.

1.11 Review and Modification of Safety Requirements

Upon NASA Contracting Officer's Technical Representative request, Lockheed Martin will participate in the review and modification of safety requirements that are to be implemented by the government including any referenced documents therein.

1.12 Procurement

The Program System Safety Engineer responsibility includes, but is not limited to, providing safety engineering support for reviewing and updating product safety requirements and criteria, and reviewing and updating safety requirements allocations to hardware and subsystems, specifically as it relates to procurement SOWs/DRDs and specifications, ICDs, and other program documentation. The source of requirements can be either requirements established by contract or requirements derived from hazard analysis. This process flows down the appropriate responsibility to assure all required product safety data is collected and provided for a thorough and complete integrated safety package.

Requisitions for procurement of chemical substances are reviewed by ESH prior to purchase in accordance with Lockheed Martin requirements, the Toxic Substance Control Act (TSCA), other relevant EPA regulations (CFR 40), and other applicable requirements, including contractual requirements. Chemical substances delivered to NASA Centers are accompanied by MSDSs as discussed in Section 1.9.

2 WORKPLACE ANALYSIS

The ESH MS, as identified in Section 1.8, provides a methodical, uniform, and consistent approach to risk identification, assessment and management. Identifying and evaluating hazards in the workplace ensures that hazards are identified and corrected in a timely manner. Lockheed Martin addresses this through risk assessments, hazard assessments, compliance reviews, environmental incident documentation, area safety inspections, Lockheed Martin Supervisor's Incident Investigation process, and the Error Prevention Council. All hazards on NASA property that are immediately dangerous to life or health will be reported immediately to the NASA safety office.

Risk Assessments

The risk assessment process identifies, characterizes, and prioritizes ESH risks for developing risk mitigation strategies. The process assesses risks to personnel, equipment, and the environment and is conducted at least annually. The risk assessment review process is standardized and documented.

The methods of hazard identification and control, e.g., hazard analysis and risk assessment, are described in the Environment, Safety and Health Management System, Element 2, Risk Assessment and the Lockheed Martin Safety Standards Manual (M-61-58): OP-44 Occupational Safety and Health, Fire Risk Management Program Self Assessment Compliance Plan.

Hazard Assessments

Hazard assessments are performed initially for each new operation in conjunction with area supervision and are updated on an as required basis. Hazard assessments identify the hazards associated with the area operations to ensure correct personal protective equipment is specified for that operational area. The steps in performing a hazard assessment include:

- Survey area to identify sources of hazards, (e.g. impact, penetration, chemical, heat, etc.)
- Identify sources of motion (e.g. machinery; sources of high temperatures that could result in burns, eye injury or ignition of protective equipment; types of chemical exposures; sources of falling objects or potential for dropping objects; etc.)
- Organize and analyze data to determine the type, level of risk, and seriousness of potential injury from each of the hazards found
- Select protective equipment that ensures a level of protection greater than the minimum required to protect employees from the hazards
- Fit the user with the protective device and give instructions on care and use of the PPE emphasizing the limitations.

The hazard assessment is described in the Lockheed Martin Safety Standards Manual (M-61-58): PD-1 Personal Protective Equipment.

Compliance Reviews

Compliance reviews assess Lockheed Martin operations that have potential safety or environmental risk (e.g., activities involving machines, electricity, elevated working positions, confined spaces, hazardous materials/waste, etc.). The reviews are designed to discover potential compliance risks, conditions or practices that could threaten the safety or health of personnel, threaten the environment, or incur Lockheed Martin site liability. The reviewers document the findings and the corrective actions. Area management is responsible for implementing corrective actions related to the compliance review.

The Compliance Review process is required by the Environment, Safety and Health Management System, Element 7, Self-assessment.

Environmental Incident Documentation

For environmental incidents, the ESH responder prepares an environmental incident report to document response to incidents that threaten human health or the environment. The report includes:

- Date and time of incident
- Location of incident
- Preparer's name
- Description of incident
- Material released and quantity
- Action(s) taken
- External notifications
- Other supporting information.

The method for responding to environmental incidents is described in the Lockheed Martin Integrated Emergency Response Plan.

Area Safety Inspections

Managers and supervisors are required to perform periodic safety inspections in order to maintain a safe workplace. Managers and supervisors have the responsibility to correct or identify additional resources to correct any deficiencies identified during the inspection.

The method for performing area safety inspections are described in the Environment, Safety and Health Management System, Element 7, Self-assessment, and in the Lockheed Martin Safety Standards Manual (M-61-58): OP-37, Safety Improvement Plan.

Lockheed Martin Supervisor Incident Investigations

The Lockheed Martin Supervisor Incident Investigation (LSMSII) process is a web-based tool for used for investigating injury and illness incidents. Following the LMSII process, the investigation will identify:

- Employee name
- Manager
- Date/time and location of incident
- Line of business/program
- Employee description of incident
- Type of accident
- Nature of injury

- Injured body part
- Manager's incident investigation
- Witness names
- Contributing factors
- Root cause
- Interim control measures
- Corrective action
- Status
- Disciplinary action
- Property damage.

The LMSII database allows for the collection and trend analysis of safety and health data.

The requirements for use of LMSII are described in CEESH FP ESH-04: Incident Reporting.

Error Prevention Council

The Lockheed Martin Error Prevention Council fosters communication for safety by managing an error prevention program. The Council is chaired by the Vice President of Product Assurance and includes representatives from across Lockheed Martin, including Space Exploration Systems. The Council processes near miss and mishap causes from across the company to identify systemic conditions for process improvement. The Council forwards actions to other organizations for consideration and implementation. For instance, the Council makes recommendations to Mission Success to develop specific Lessons Learned Bulletins. Additionally, identified command media deficiencies are forwarded to the appropriate actionee. As an example, the Council forwarded the need for Drop Mitigation command media to the Six Sigma Process that led to the development of Drop Mitigation requirements for Lockheed Martin.

2.1 Hazard Identification

Procedures for identifying and evaluating hazards are as follows:

- Safety/Housekeeping Inspection for Office Areas: A checklist used by supervision to inspect their areas for hazardous conditions, and to record corrective actions taken
- Safety/Housekeeping Inspections for Manufacturing, Test, and Laboratory Areas: A checklist used by supervision to record the inspection results and document corrective actions taken
- ESH compliance reviews: Reviews designed to evaluate the effectiveness of the organization's injury and illness program, as well as other facets of the ESH program
- Review of plans and procedures: Proposed modifications to facilities and major equipment are reviewed for ESH implications prior to approval. Whenever possible, the operational design is modified to mitigate potential risks. If design modifications cannot or do not eliminate the risk, administrative controls are implemented to protect the employees. If neither engineering controls nor administrative controls adequately address the risk, employees are provided with proper protective equipment to minimize injury or illness from the hazards associated with their tasks

- Review of new or modified equipment, processes, procedures, and substances: New and/or modified equipment, procedures, and substances are evaluated to ensure personnel safety prior to implementation
- Test Operations: Monitor test operations to control risk to personnel
- Subcontractor Activities: Monitor subcontractors at Lockheed Martin work locations
- Test Procedures: Review and approve test procedures prior to operations
- LMSII: Perform incident and mishap investigations related to personnel safety and environmental protection.

The Program System Safety Engineer also performs Hazard Identification. The following describes System Safety's role with respect to hazard identification.

A System Safety Engineer (SSE) is assigned responsibility and accountability for system safe design, development, documentation, verification, test, operation, and SES product safety. The SSE ensures compliance to safety requirements imposed and derived necessary for a successful mission. Safety assessment is the SSE's top priority to support 100% mission success. The SSE is held responsible for the safety of the hardware and the quality of the safety assessment, and reviews the readiness, performance, and pedigree of the product.

- The SSE is the "focal-point" for the resolution of any project safety issue pertaining to product hardware
- The SSE will appeal any decision that in their judgment may adversely affect product safety. In no case will the appeal of an issue, judged to be safety-critical by an SSE, be dismissed or categorized as inappropriate behavior.

The role of the SSE includes the following functions and responsibilities:

- Support development of all imposed or derived safety requirements, including interfaces and verification requirements. Ensure safe product compatibility across interfacing components
- Ensure design, analyses, and procedures for test, demonstrations, inspections, and manufacturing, and incorporate the appropriate safety verification
- Ensure maintenance of product safety requirement waivers and deviations. Only accept deviations that conclusively show no adverse effect on product safety. Maintain in-depth knowledge of the safety assessment over its life cycle, and investigate/resolve any concerns
- For commercial off the shelf (COTS) products lacking the traditional historical pedigree, bring to management's attention any use of COTS that the SSE deems to be unacceptable risk
- Ensure verification methods (test, analysis, demonstration, inspection) are decisive, and adequate to characterize safety performance and support Mission Success
- Elevate hardware safety concerns, which cannot be resolved through normal channels, to the program manager
- Monitor test operations to control residual risk
- Perform incident and mishap investigations related to product hardware and related systems.

The SSE has the responsibility to prepare the hazard analyses and document non-compliance.

SSE tasks include, but are not limited to:

1. Identification of hazards in design concepts and throughout development and production by adequate analysis, testing, quality assurance, and product support
2. Evaluation of product and process designs, using design standards, design reviews, historical data, and experience on comparable products to ensure the control or elimination of potential hazards
3. Verification of product safety requirements by testing, analysis, or other methods that components, subsystems, and end products meet safety objectives established for the program and product.

Any combination of the above listed procedures and processes may be used to compile an inventory of hazards associated with the SES program. The inventory will be reported to NASA upon request.

2.2 Inspections

Line management conducts manufacturing facility inspections and desk/board facility inspections. Area supervisors are responsible for correcting the identified hazards. ESH engineers
periodically assess discrepancy reports for severity, probability, and adequacy of the corrective actions. The line manager ensures that corrective actions are tracked to closure and that they are effective.

ESH engineers are responsible for conducting assessments to ensure compliance to ESH requirements. Discrepancies are recorded and status of corrective action implementation is tracked until closed.

While at NASA Centers, Lockheed Martin safety inspections/walk-downs shall be performed and discrepancies corrected for Lockheed Martin assigned work areas. Discrepancies shall be documented and addressed prior to the start of the affected steps. The inspections will identify:

- Discrepancies between observed conditions and current requirements
- New or modified hazards.

2.3 Employee Reports of Hazards

Personnel have the freedom and authority to:

- Identify and record any problems relating to the personnel safety, product, process, or quality system
- Suspend operations, recommend, or provide solutions
- Verify the implementation of solutions
- Control further operations or processing, delivery, or installation of nonconforming products until the deficiency or unsatisfactory condition has been dispositioned.

Employees are encouraged to identify areas in which safety can be improved. Employees at Lockheed Martin facilities have the capability to submit service requests to the Facility Operations & Services organization to provide repairs to faulty equipment or to make facility modifications to eliminate an identified workplace hazard.

In addition, a Safety Hotline number is provided to report any unsafe or hazardous condition. The caller may, at his or her own discretion, remain anonymous; however, in no case will there be reprisal to an employee for reporting a suspected or known unsafe condition.

3 MISHAP INVESTIGATION AND RECORD ANALYSIS

3.1 Mishap Investigation

Onsite at NASA Centers or at other Lockheed Martin facilities, the involved employee notifies, as soon as practical, his or her supervisor, facility manager and/or the Site Safety Representative with an immediate report describing the where, what, and when aspects of the occurrence. This includes accidents, fires, hazardous chemical spills, and any other ESH-related emergencies. For incident/accidents involving injuries to personnel, the employee reports to the site's medical facility and the Lockheed Martin Supervisor's Investigation (LMSII), or equivalent, process is initiated. LMSII is published on the Lockheed Martin intranet and is a systematic process of identifying root causes of incidents/accidents and near-miss occurrences, recommending corrective actions, communicating the results, and implementing corrective actions to prevent similar events from occurring. Implementation of this process determines root causes and mitigating causal factors. This enables supervisors to develop corrective actions to eliminate hazards in their work areas. For product safety, the supervisor is also responsible for performing an investigation and for issuing a Flash Notice, or equivalent, to the Lockheed Martin point of contact, and a report of the incident is forwarded to the customer contracting officer. Flash Notices are to be issued before end of shift.

The customer contracting officer shall be notified of any mishap arising out of customer contract work performed resulting in fatality, lost-time occupational injury, lost-time occupational disease, contamination of customer property, or property loss of $25,000 or more. Mishap investigation findings and corrective actions will be reported to the customer following the Lockheed Martin mishap investigation.

3.1.1 Prevention of Recurrence of Mishaps

The ESH department is the central location/depository for reports and records pertaining to occupational injuries and environmental incidents.. LMSII reports are reviewed and approved by ESH. Investigations that are not complete, including identification of root cause and implementation of corrective action, are not approved until completed.

ESH engineers are present in work areas and are integrated into local operations. This integration allows for early identification of potential risks and enables mitigation for injury prevention. ESH engineers routinely communicate with Lockheed Martin lines-of-businesses and participate in project team activities to review and evaluate ongoing operations.

Depending on the nature of the incident, company-wide stand-downs are implemented to solicit and address input from employees regarding process improvements. In the aftermath of the TIROS incident, a stand-down was held. Numerous comments and suggestions for improvements resulted from the stand-down. The comments were input to Mission Success and tracked to resolution resulting in systemic improvements across Lockheed Martin to include:

- Performance of Functional Failure Modes and Effects Analysis (FFMEA) for equipment involved in critical product operations
- Validation of handling procedures prior to use

- Error Prevention training certification to provide tools to personnel to avoid human errors; these tools are built into the test conduct process
- Training and certification of Test Conductors and Product Assurance personnel
- Implementation of Pretask briefings (Huddles)
- Inspection pre and post movement
- Increased presence of ESH in the work area
- Increased communication to personnel regarding personnel safety and health
- Increased management accountability for safety and health performance.

In addition, ESH publishes bulletins that focus on key ESH issues and summarizes selected accident, illness, and injury cases from the previous month as a lessons learned tool. These bulletins are published electronically and are available to all employees.

3.1.2 NASA Form 1627

A NASA Mishap Report (NASA form 1627), or an equivalent LMSII report, shall be submitted for mishaps occurring on NASA property and that meet the criteria predefined in Section 3.1 Within 24 hours of the occurrence, the information required on the unshaded portion of form 1627 will be obtained and forwarded to the NASA Program Safety Office. An investigation of the mishap will be conducted under Lockheed Martin supervision to determine the root cause of the mishap. Within 10 days of the occurrence, the information regarding the direct/root cause and planned corrective action will be forwarded to the NASA Program Safety Officer. If NASA management deems it necessary to appoint a mishap investigation board, Lockheed Martin will provide support as requested.

3.1.3 Near Misses

A near miss report is completed and distributed to the appropriate NASA offices for incidents occurring at a NASA Center. The first-line supervisor, who is responsible for identifying the root cause and corrective action, investigates near misses. The supervisor is also responsible for implementation of the corrective action and for tracking the corrective action to closure.

3.2 Trend Analysis

The LMSII process allows for automatic compilation and trending of injury data on a real time basis. The Lockheed Martin ESH department reviews the data, performs trend analyses, and prepares reports for senior management on a routine basis. LMSII reporting tools allows for status of safety and health performance and provides focus for management. The Fishbone Analysis tool (Fig. 3.2-1), gives an example of how injury and illness causes are evaluated for root cause and corrective action.

Upon request, Lockheed Martin will provide the following metrics to NASA at the monthly Program Management Review.

- OSHA Recordable Rates
- OSHA Day Away Cases Rate
- OSHA Severity Rate.

Per NPG 8715.3, Appendix H, Lockheed Martin will provide the following:

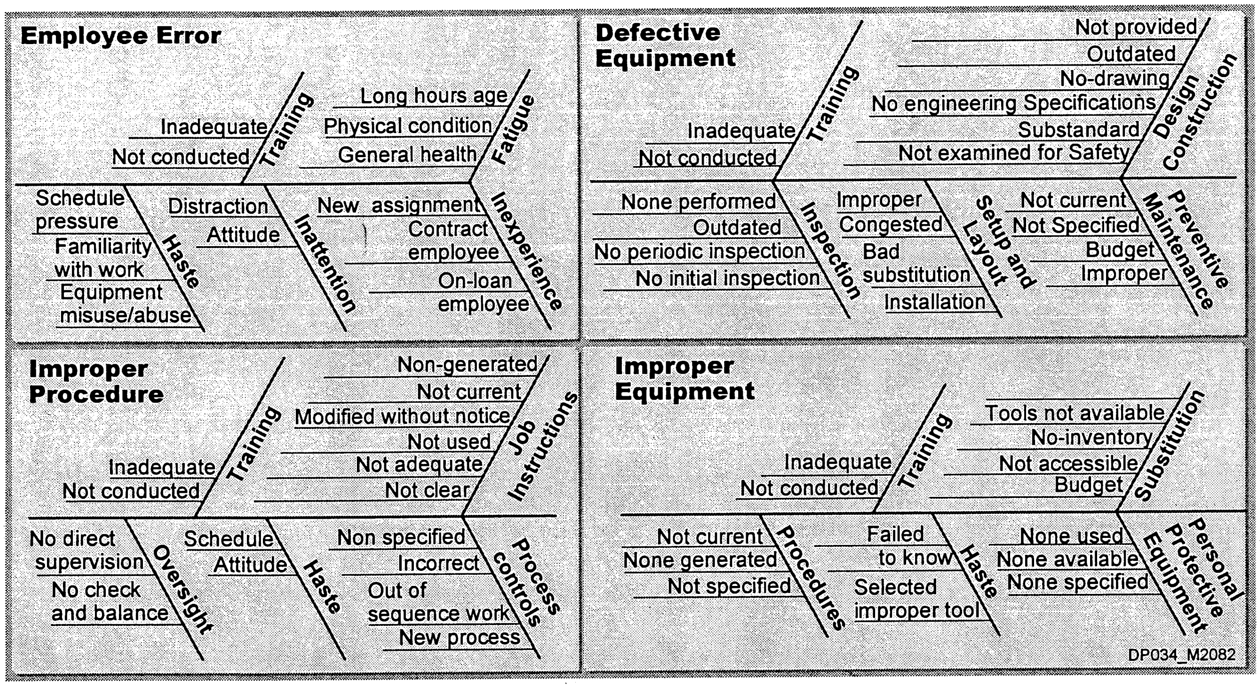

Fig. 3.2-1 Fishbone Analysis Defines Root Causes and Provides Appropriate Corrective Actions.

- Accident/Incident Summary Report. New and open mishaps related to the customer's program will be described in summary form along with current status. A report will be generated and delivered to the customer contracting officer as required by contract.
- Log of Occupational Injuries and Illnesses. The Lockheed Martin ESH department will provide a copy of its annual summary of occupational injuries and illnesses to the customer contracting officer as required by contract within 45 days after the end of the year to be reported.

4 HAZARD PREVENTION AND CONTROL

Lockheed Martin managers work with other support contract and NASA managers to promote a safe and healthful work environment in onsite and offsite facilities. This includes communicating applicable information related to ESH policies/procedures, best practices, lessons learned, hazards and their discrepancies, and corrective actions. LMSII, Lessons Learned databases, Flash Notices, Lockheed Martin Mission Success Bulletins, and Government Industry Data Exchange Program documents are some of the tools used to identify unique hazards for projects and recommend corrective action. For risk management purposes, information regarding identified hazards (including discrepancies and corrective actions) related to Lockheed Martin SES operations at the Center, will be submitted electronically to the Center for collection in the Center's information data system.

4.1 Appropriate Controls

The hazard reduction precedence sequence used by Lockheed Martin is based on the severity of the hazard. An imminent hazard requires immediate abatement and, if necessary, evacuation of employees until the hazard is mitigated. A non-imminent hazard may be addressed through the Service Request process, through safety specific communications, through awareness briefings, or other applicable means.

If a residual risk to personal safety is identified during a hazard analysis, the finding is communicated to the employees at risk and a process to mitigate the risk is initiated. Three common types of control that can be implemented to mitigate a hazard to personnel safety are listed below. They are listed in the sequence of preferred implementation. A fourth type of control, not often considered, is listed last.

1. Engineering—A mechanical device that isolates physical contact between a person and a hazard
2. Administrative—Regulations, policies, procedures, standards, safety rules, warning signs, barriers, etc. that are designed to warn employees of potential hazards
3. Personal Protective Equipment (PPE) —Protective devices designed to reduce or eliminate hazardous (chemical, physical, or radiological) conditions
4. Behavior—Actions performed by employees in the workplace that contribute to the safety or hazards of a particular operation/task.

If a residual risk to the environment is identified during a hazard analysis, a process to mitigate the risk is implemented with the goal to first eliminate discharge or emission to the environment through engineering controls; second, to eliminate the risk through procedural controls; and third, to allow discharge or emissions through regulatory permitting process or other allowable methods.

System Safety Engineering performs Hazard Identification that is detailed in the Product Assurance Plan. The SSE performs hazard analyses with emphasis on safety in design and process, at a minimum, throughout integration to launch, including interfaces with support equipment and facilities. As hazards are identified, they are addressed with controls to mitigate the hazard. These are documented in contractually required safety data packages.

The following order of precedence is followed for the resolution of identified hazards:

- Hazard Elimination—Hazard sources or hazardous operations are eliminated
- Design for Minimum Hazard—Design has ensured inherent safety through appropriate design features, materials and parts selection, and safety factors. Damage control, containment, and isolation of potential hazards have been implemented
- Safety Devices—Known hazards, which could not be eliminated by design, are reduced to an acceptable level by use of appropriate safety devices as part of the system, subsystem, or equipment
- Warning Devices—Where it is not possible to preclude the existence or occurrence of a known hazard, warning devices are employed for the timely detection of hazardous conditions and the generation of adequate warning signals
- Special Procedures—Where it is not possible to reduce the magnitude of an existing or potential hazard by design or by use of safety and warning devices, special procedures are developed to counter hazardous conditions for personnel and the protection of products.

Engineering analyses, sampling, professional judgment, or other appropriate means will determine the effectiveness of one or any combination of the controls listed above. Lockheed Martin SES operations at a NASA Center will be coordinated with safety, health, and environmental services, and emergency services per contract requirements, and if appropriate controls cannot be implemented.

4.1.1 Hazardous Operations

Hazardous operations are evaluated, at a minimum, for the following basic requirements: hazardous operation characterization, verification of training and certification, development of procedures, and use of permits. In addition, new or non-routine hazardous operations are evaluated by ESH to determine potential risk to personnel health and safety and to ensure appropriate
controls are in place to mitigate the risk. Accordingly, the SSE reviews new or non-routine hazardous operations when a potential loss of critical product has been determined. The PSO is responsible for notifying area personnel when hazardous operations are to be performed and when hazardous conditions may exist.

During the project test planning process, the SSE will identify operations that are hazardous. A list of hazardous operations planned for conduct at NASA Centers is compiled in a list that is included in the project safety data package. The test procedure will identify the specific hazardous operation along with the appropriate controls/steps to mitigate the hazard. ESH and the SSE review and approve applicable procedures before they are performed. Procedures performed at NASA Centers are also subject to review and approval by the Center Safety Office before they are performed.

Test team required attendees and allowed optional participants are listed in each procedure, and the team test reviewers ensure the proper personnel are listed to perform the tasks.

4.1.2 Written Procedures

In addition to what was identified in Section 4.1.1, supervisors ensure that permits required for hazardous operations are approved before any work is attempted. Permits required by regulation (e.g., wastewater discharge, hazardous waste) as well as permits required by command media for hazardous operations (e.g., hot work, permit required confined space entry) are also obtained prior to the start of operations. Restrictions on the application of permits are detailed in the appropriate command media.

Program personnel perform test and interfacility movement of critical products in accordance with written procedures. The test planning process detailed in 2.3.8.1-T2-Test-1.0-P, Test Engineering Process, dictates a structured process for development of test procedures including test plans, test procedure development, test readiness, and test conduct.

4.1.3 Protective Equipment

Personal protective equipment is used only when engineering and administrative controls cannot be accomplished and are insufficient in protecting the employee from physical or toxic hazards. Lockheed Martin employees are trained and required to wear protective equipment as necessary to protect them from the hazards of their work environment. Hazard assessments are performed by ESH to determine the specific protective equipment necessary for the work environment in accordance with local ESH operating procedures and test procedures. Precautionary steps to safeguard employees are included in the operating procedures/instructions. Employees are trained on the proper use, inspection, and maintenance of the protective equipment selected for their work environment. Lockheed Martin procedures for Personal Protection and its associated requirements, including any recordkeeping requirements are documented in the Lockheed Martin Safety Standards Manual, (M-61-58) Protective Devices, PD-01 through PD-16.

4.1.4 Hazardous Operations Permits

The application of permits to Lockheed Martin operations is defined in command media. For instance, the hot work permit process defines applicability of the permit and how the permit is acquired. Permit required confined spaces are also labeled at the location to warn personnel approaching the confined space. Training and certifications required for these operations comply with Section 6, Safety and Health Training. Permit processes at NASA Centers may differ from Lockheed Martin processes, and the NASA Center processes will take precedence for operations at NASA Centers. SES projects do not use asbestos materials that pose a potential exposure to personnel. Procedures for hazardous operations at a NASA Center will be available to the customer. Safety requirements for these operations will be coordinated between Lockheed Martin and NASA.

Hazardous Waste is managed in accordance with federal, state, local regulations, the ESH MS, other applicable command media, and contractual requirements. In particular, new or modified waste generation locations, activities, or processes are identified at the earliest possible time, and prior to start of construction or process modifications to ensure appropriate waste management. The supervisor must ensure their employees are current with hazardous waste training requirements. Hazardous waste generated by Lockheed Martin is segregated from non-hazardous waste and is dispositioned in accordance with Lockheed Martin Corporate requirements. For operations at NASA Centers, the environmental services office will be notified of any new or modified hazardous waste operation.

New or modified emissions and discharges to the environment are also managed in accordance with federal, state, and local regulations, the ESH MS, other applicable command media, and contractual requirements. Compliance with terms and conditions of wastewater and air permits is addressed through training and ESH participation in design, test, and procedure reviews. Participation in design ensures adequate lead-time for processing permits through the appropriate agencies. Procedures to minimize or eliminate pollution are identified in the integrated Lockheed Martin—Denver Operations Materials Containment Plan/Stormwater Management Plan/Spill Prevention, Controls and Countermeasures Plan. Requests for acquisition of restricted and hazardous materials are approved by ESH, and a less hazardous material is recommended, whenever possible. Spills, leaks, or other releases of hazardous or regulated materials are promptly report to the facility emergency response organization or coordinator to ensure proper measures are taken to ensure personnel health and safety and to mitigate and report the release.

4.2 Facilities Maintenance

Lockheed Martin SES maintains no NASA Center facilities. ESH is responsible for implementing programs that ensure hazards in facilities operated by Lockheed Martin are appropriately controlled. ESH approves building modifications to ensure safety requirements are met.

4.3 Preventive Maintenance

Preventative maintenance is scheduled through a computer generated database that tracks equipment maintenance due dates. Maintenance is performed in accordance with manufacturer's recommendations, industry standards, command media, or task specific procedures. When facility equipment is due for maintenance it is scheduled for least impact to ongoing programs. In the event an anomaly is found during the maintenance, evaluations begin to determine options for use, repair, or replacement. If the anomaly renders the equipment unsafe, it is tagged out. If a Flash Notice is generated as a result of SES preventive maintenance operations, the notice will be shared with the NASA.

4.4 Medical Program

Lockheed Martin provides a medical surveillance program to ensure employees working with toxic substances or harmful physical agents are not adversely affected by exposure. Periodic examinations are made available to employees with the frequency and type of examination defined by the nature of the exposure.

Lockheed Martin—Denver Operations medical services provided include:

- Medical exams and testing for employees as required by federal (including OSHA and DOT), state, local, and ESH requirements
- Treatment of occupational injuries and illnesses
- Advising employees on medical issues.

Emergency first aid, cardiopulmonary resuscitation, and emergency response are provided by Lockheed Martin—Denver Operations Plant Protection. Plant Protection maintains a staff of trained emergency medical technicians and an ambulance to provide immediate response to medical emergencies.

5 EMERGENCY RESPONSE

Lockheed Martin—Denver Operations identifies and takes preparatory actions to ensure an organized response in the event of induced or natural emergency or disaster events. Actions focus on minimizing the exposure of public/personnel, the environment, and assets to unwarranted risk, injury or damage, while maximizing recovery of operational capability.

The Lockheed Martin—Denver Operations Crisis Management Plan documents requirements and procedure response to emergencies. Lockheed Martin—Denver Operations employees follow the host site Crisis Management Plan, unless other agreements are in place. The Crisis Management Plan identifies the chain of command and the response process for various emergencies. In the event of an emergency, an employee must:

- Move to a safe location
- Report incident to supervisor, if immediately available
- Call the local facility's emergency number
- Stay on the telephone line until instructed to hang up by the dispatcher.

Upon receipt of information to Plant Protection, the appropriate Emergency Response Teams (ERT) responds to the emergency. Lockheed Martin ERT employees receive specialized training in any one, or all of the following fields: first aid, automatic electronic defibrillator, and 29 CFR 1910.120 (HAZWOPER). In addition to recertification training, the ERT members hold emergency response drills and are evaluated for emergency preparedness.

Methods for notifying NASA Center emergency forces are to be briefed to visiting Lockheed Martin employees by the NASA Center host.

6 SAFETY AND HEALTH TRAINING

The goal of the training program is to ensure qualified personnel are available to perform their assigned tasks and to operate facilities in a safe and reliable manner. Training focuses on understanding and applying safe work procedures to the task, recognizing and dealing with any associated hazards, and being familiar with the appropriate PPE and/or countermeasures to safely and effectively deal with hazards encountered on the job.

An ESH training matrix derived from regulatory requirements and from training needs identified through the skill certification board is used to assist managers/supervisors in determining an employee's ESH training needs. Where training is required, employees are trained in accordance with regulatory, corporate, and applicable contractual requirements prior to performing the task. Training requirements are dependent on the employee's assigned job function, resulting in more detailed training for hands-on operators as opposed to general training for new employee orientation. Similarly, training requirements for management will differ from that required for production workers. A comprehensive training and course listing identifying job function and associated training requirements can be found in AP04.18 (refer to Attachment 5).

Existing training resources available through Lockheed Martin, NASA, and the contractor community are fully utilized to the extent possible to ensure consistency of messages, understanding of the overall ESH picture, and minimizing contract costs. Training requirements for Lockheed Martin operations planned at a NASA Center are coordinated with NASA, and Lockheed Martin personnel complete training to meet NASA Center requirements. Lockheed Martin training that meets the requirements of a NASA Center training certification is not repeated.

Lockheed Martin provides employees with training in PPE and other courses as needed to safely accomplish assigned duties. Specific to PPE, a basic course is provided, and specific PPE training is provided where more severe hazards can be encountered, e.g., courses in respiratory protection, fall protection, and electrical safety. Class instruction includes hazard recognition and PPE inspection, use, maintenance, and limitations.

Supervisory duties include:

- Identify training requirements for employees
- Ensure employees are current with training requirements
- Monitor certifications and training records.

ESH duties include:

- Performing hazard assessments to define PPE requirements
- Define safety training requirements for tasks
- Provide assistance in developing worker training
- Conduct training, as applicable
- Conduct periodic assessments of ESH programs, including PPE.

Training records are maintained in a database on the Lockheed Martin intranet. Training materials and training records are available for NASA review upon request.

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Safety Performance

Lockheed Martin has improved its safety and health record during the last three years (Fig. Att1-1) and set targets through 2008 to work toward the goal of zero injuries. To meet these targets, ESH resources have been increased with an emphasis on creating greater awareness of personnel safety in the workplace, including management accountability.

Incident/Accident History

Lockheed Martin's most recent (January 1, 2004 through May 31, 2004) incidents resulting in lost time are reflected in Fig. Att1-2. A determination of root cause has been established for these incidents allowing Lockheed Martin to focus on these risk areas to enable continuous improvement.

Major subcontractor information is also provided in Fig. Att1-2.

In addition to the incidents resulting in lost time, Lockheed Martin had a serious incident with the TIROS satellite in 2003 when it fell from its support to the floor. A mishap investigation was immediately initiated and numerous mitigations were put in place as corrective
actions. Refer to Section 3.1.1 Prevention of Recurrence of Mishaps for more information related to the results of the TIROS investigation.

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ATTACHMENT 2—PRIMARY LOCKHEED MARTIN ESH DOCUMENTS

Attachment 2 Primary Lockheed Martin ESH Documents*

Lockheed Martin Document No.	Title
Lockheed Martin Corporate Policies and Functional Procedures	
CPS-015	Environment, Safety and Health
ESH-01	ESH Management System
ESH-02	Real Estate Transactions
ESH-03	Metrics
ESH-04	Incident Reporting
ESH-05	Contractor Management
ESH-06	Waste Disposal
ESH-07	Commercial Motor Vehicle Safety
ESH-08	Hazardous Materials Transportation
ESH-09	ESH Host-Tenant Responsibilities
ESH-10	Environmental Safety and Health Self-assessment Process
CPS-527	Records Management
SSC Policies	
SSC 1.7.8	Environment, Safety & Health
AS-P-04.01	Environmental Protection
AS-P-05.04	Nonscheduled Visits from Official Agencies
HR-P-10.01	Safety Program
HR-P-10.04	Chemical Tracking and Management System
HR-P-10.08	Hazard Communication Program
HR-P-10.10	Experiments and Testing Involving Risk to Humans
HR-P-10.11	Control of Ionizing Radiation Sources
HR-P-10.12	Laboratory Chemical Hygiene Program
HR-P-10.13	Occupational Ergonomics Program
Procedures	
AM 02.10	Ordnance Materials
AM 02.12	Hazardous Materials or Chemicals
AM 02.13	Radioactive Materials and Radiation Generating Equipment
AP 01.08	System Safety Standard
AP 04.18	Astronautics Standard Procedures Training, Certification, Education
AS 04.01	Environmental Management
AS 04.03	Environmental Regulatory Requirements
AS 04.05	Environmental Communications
AS 04.07	Environmental Controls and Corrective Actions
AS 04.08	Environmental Emergency Response
AS 04.09	Environmental Monitoring
EN 04.01	Engineering Process Specifications/Standard Processes and Nonstandard Processes
EN 04.02	Standardization of Parts, Materials, and Processes
EN 04.03	Part and Material Substitution
EN 04.06	Engineering Material Specifications
EN 04.08	Nonstandard Request/Authorization (NSR/A)
EN 04.10	Parts, Materials, and Processes Control Board (SLS/Titan)

Lockheed Martin Document No.	Title
EN 06.02	Test Procedures
EN 06.06	Proofload and Inspection Requirements for Material Handling Equipment
2.3.8-T1-SE-1-P	Verification Processes
2.3.8.1-T2-TE-1.0-P	Test Engineering
2.3.8.1-T2-TE-1.3-G	Test Like You Fly
EG1.2.4.2-G1	Test Engineering Guidebook and Appendices
EG3.5.3.1	Functional Failure Modes Effects Analysis Guidebook
HR 10.02	Asbestos Control
HR 10.03	Vehicle Accident Reporting
HR 10.04	Support to Contractual Safety Tasks
PA 05.06	Mishap and Near Miss Reporting
HR 10.06	Illness, Injury, or Death of Company Employees
HR 10.07	Prescription Safety Glasses
HR 10.08	Protective Footwear-Safety Shoes
HR 10.09	Occupational Hearing Conservation Program
HR 10.11	Contractor Safety Program
HR 10.12	Occupational Safety & Health Assessments and Audits
Practices	
	Astronautics Crisis Management Plan
	Integrated Environmental Emergency Response Plan
M-86-2	Chemical Information System Handbook
M-61-58	Lockheed Martin Safety Standards M-61-58
Electrical	
E-01	Portable Electrical Tools and Electrical Apparatus
E-02	Lighting (General and Emergency)
E-03	Radio Frequency Radiation
E-04	Laser Beams
E-05	Electrical, General
Mechanical	
M-01	Proof, Checking Ground Support Propellant and Gas System Piping
M-02	Flexible Hoses
M-04	Fluid System Pressure Testing
M-05	Cranes and Hoisting Apparatus
M-06	Local exhaust Ventilation
M-07	Hydrostatic Pressure Testing of Missiles
M-09	Elevator Inspection and Test
M-10	Inspection and Testing of Portable Extension, Step Ladders
M-12	Excavation and Shoring
Office	
OF-1	Office Safety
OF-2	Video Display Terminals
Operational	
OP-01	Scaffolds
1.3.3-T1-ESH-9.0-S	Confined Space Entry
OP-04	Grounding Flammable Liquid Dispensing Equipment

Lockheed Martin Document No.	Title
OP-05	Receiving, Shipping, Storing, Handling, Transporting, Testing, and Disposing of Ordnance Items
OP-06	Slings, Chains, Rope
OP-07	Compressed Gas Cylinders
OP-08	Warehousing
OP-09	Ultraviolet Radiation
OP-10	Radiological Control of X-Ray Generating Equipment
OP-11	Abrasive Wheels
OP-14	Spray Painting
OP-15	Bottled Drinking Water
OP-18	Contact Lenses - Restriction
OP-19	Chemical Labeling
OP-20	Compressed Air
OP-21	Access Control to Hazardous Areas
OP-22	Chemical Laboratory Safety
OP-23	Aerosol Spray Cans
OP-26	Restricted Materials or Chemicals
OP-29	Testing with Humans as Subject
OP-30	Accident Prevention Signs
OP-31	Color Schemes for Marking and ID
OP-32	The Control of Hazardous Energy - (Lockout-Tagout)
OP-33	Use of Danger and Warning Tags
OP-35	Reporting and Correcting Unsafe Conditions
OP-36	Housekeeping
OP-37	Safety Improvement Plan
OP-38	Buddy System and Two Man System
OP-39	Preoperational Briefing of Personnel
OP-40	Contractors
OP-41	Medical Surveillance Program
OP-42	Bloodborne Pathogens
OP-43	Process Safety Management
OP-44	Occupational Safety and Health, Fire Risk Management Program Self Assessment Compliance Plan
OP-45	Potentially Hazardous Activities - Plans
OP-46	Heat and Cold Stress
Protective Devices	
PD-01	Personal Protective Equipment
PD-02	Cleaning and Inspection of Personal Protective Equipment
1.3.3-T1-ESH-63.0-S	Respiratory Protection
PD-04	Face Shields
PD-05	Fall Protection
PD-06	Hard Hats
PD-07	Helmets and Hand Shields
PD-08	Eye and Face Protection
PD-09	Containers for Flammable or Hazardous Materials
PD-10	Occupational Hearing Conservation
PD-11	Insulating Gloves, Electrical

Lockheed Martin Document No.	Title
PD-12	Protective Glove, Storable Propellant
PD-14	Footwear
PD-15	Emergency Showers and Eyewash
PD-16	Respiratory Protection SCBA Use and Inspection
Vehicles	
V-1	Operation of Emergency Motor Vehicles
V-2	Operation of Company Vehicles
V-3	Powered Industrial Trucks

*The most current version of these documents, or their replacement documents, will be in effect for work performed under this contract.

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ATTACHMENT 3—PRIMARY GOVERNMENT DOCUMENTS

Attachment 3 Primary Government Documents

Government Documents Document No.	Title
NPR 8715.3	NASA Safety Manual
29 CFR 1910 and 1926	Occupational Safety and Health Federal
40 CFR	Environmental Management Regulations
52.233-3	(Section I Clause) Hazardous Material Identification and Material Safety Data – Alternate 1
FAR 52.222-4	Contractor Work Hours and Safety Standard Act – Overtime Compensation
NASA FAR 1852.223-70	Safety and Health
NASA FAR 1852.223-73	Safety and Health Plan

ATTACHMENT 4—MATERIAL SAFETY DATA

Lockheed Martin Space Systems Fed Standard 313D
The intent of this cover sheet is to provide those data directed by
Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA
Program: HST/ HRVDM/ HDV

Contract / RFP #: NNG0461779R
LM Subcontractor if applicable:

Sub's MSDS #:

LM MSDS/ CRN #: T 05871

Material Description: Copper Beryllium Wrought Alloy

Material Supplier: BrushWellman

Suppliers Part #: **

Suppliers CAGE: **

National Stock #: **

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Title of Spec:

DOT Proper Shipping Name: See comments

DOT Hazard Class: See comments

DOT PK Group
Land: See comments
Air: See comments
Water: See comments

UN/ NA ID #: See comments

Comments: There are no U.S. Department of Transportation hazardous material regulations that apply to the packaging and labeling fo this product as shipped by BrushWellman.

** = Not available at time of proposal

T05871

BRUSHWELLMAN
ENGINEERED MATERIALS

MATERIAL SAFETY DATA SHEET - NO. A10

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Copper Beryllium Wrought Alloy

SYNONYMS Copper Beryllium Alloy
Beryllium Copper Alloy
Copper Alloy

CHEMICAL FAMILY Alloy

24-HR. EMERGENCY ASSISTANCE
Transportation Emergency
Call Chemtrec at:
Domestic: (800) 424-9300
International: (703) 527-3887
Other Emergency
Call Brush Wellman at: (800) 862-4118

Revised: 01-01-02
Replaces: MSDS A10 (02-15-01)

CUSTOMER SERVICE
Brush Wellman Inc.
Product Stewardship Department
17876 St. Clair Avenue
Cleveland, Ohio 44110
Phone: (800) 862-4118
Fax: (216) 383-4091
Websites www.brushwellman.com
www.befacts.com

2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL COMPOSITION (Percent by Weight)

		BRUSH WELLMAN PRODUCT NAME OR ALLOY NUMBER (Copper Development Association UNS Number)							
CONSTITUENTS	CAS Numbers	10 (C17500)	10X, Q-Max (C175000)	165 (C17000)	170	171 (C17450)	174 (C17400) (C17410) (C17420)	25, 190, 290, (C17200)	3 (C17510)
Copper	7440-50-8	96.6 - 97.2	96.3 - 96.9	97.8 - 98.2	97.4 - 97.8	97.4 - 99.4	98.9 - 99.5	97.6 - 98.2	97.2 - 98.4
Cobalt	7440-48-4	2.4 - 2.7	2.4 - 2.7	0.2 - 0.35	0.09	--	0.35 - 0.6	0.2 - 0.35	--
Nickel	7440-02-0	--	--	--	0.25 - 0.45	0.5 - 1.4	--	--	1.4 - 2.2
Beryllium	7440-41-7	0.4 - 0.7	0.4 - 0.7	1.6 - 1.79	1.9 - 2	0.15 - 0.5	0.15 - 0.5	1.6 - 2	0.2 - 0.6
Zirconium	7440-67-7	--	0.3	--	--	0 - 0.5	--	--	--

Hazard Communication regulations of the U.S. Occupational Safety and Health Administration apply to this product.

NOTE: As used in this Material Safety Data Sheet, the term "particulate" refers to dust, mist, fume, fragments, particles and/or powder.

3. HAZARD IDENTIFICATION

3.1 EMERGENCY OVERVIEW

Metallic product which poses little or no immediate hazard in solid form. See label in Section 16. If the material is involved in a fire; pressure-demand self-contained breathing apparatus and protective clothing must be worn by persons potentially exposed to the airborne particulate during or after a fire.

3.2 POTENTIAL HEALTH EFFECTS

Exposure to the elements listed in Section 2 by inhalation, ingestion, and skin contact can occur when melting, casting, dross handling, pickling, chemical cleaning, heat treating, abrasive cutting, welding, grinding, sanding, polishing, milling, crushing, or otherwise heating or abrading the surface of this material in a manner which generates particulate.

Exposure may also occur during repair or maintenance activities on contaminated equipment such as: furnace rebuilding, maintenance or repair of air cleaning equipment, structural renovation, welding, etc.

Particulate depositing on hands, gloves, and clothing, can be transferred to the breathing zone and inhaled during normal hand to face motions such as rubbing of the nose or eyes, sneezing, coughing, etc.

3.2.1 Inhalation

Particulate containing those elements listed in Section 2 can cause irritation to the nose, throat, lungs, and mucous membranes. Inhalation of this particulate may cause metal fume fever (high temperature, metallic taste, nausea, coughing, general weakness, muscle aches, and exhaustion), bronchitis, chills, decreased pulmonary function, and asthma-like symptoms.

Beryllium: The beryllium in this product is not known to cause acute health effects. Inhaling particulate containing beryllium may cause a serious, chronic lung disease called Chronic Beryllium Disease (CBD) in some individuals. See section 3.2.5 Chronic (long-term health effects).

Cobalt: May cause asthmatic attacks due to allergic sensitization of the respiratory tract. May cause asthma and shortness of breath.

Copper: Inhalation of particulate containing metallic copper can cause ulceration and perforation of the nasal septum.

Nickel: Can cause headaches, dizziness, and difficult breathing. Inhalation of nickel and nickel compounds is associated with nasal and lung damage and cancer. Symptoms may include coughing, sore throat, and shortness of breath.

Zirconium: Inhalation of zirconium compounds may cause pulmonary granulomas.

3.2.2 Ingestion

Ingestion can occur from hand, clothing, food and drink contact with particulate during hand to mouth activities such as eating, drinking, smoking, nail biting, etc.

Beryllium: The health effect of ingestion of beryllium in the form found in this product is unknown.

Cobalt: May cause gastrointestinal irritation with nausea, vomiting and diarrhea. May cause allergic reaction.

Copper: Copper ingestion causes nausea, vomiting, abdominal pain, metallic taste, and diarrhea. Ingestion of large doses may cause stomach and intestine ulceration, jaundice, and kidney and liver damage.

Nickel: Causes gastrointestinal irritation with nausea, vomiting and diarrhea.

Zirconium: May cause gastrointestinal irritation with nausea, vomiting and diarrhea.

3.2.3 Skin

Skin contact with this material may cause, in some sensitive individuals, an allergic dermal response. Skin contact may cause irritation. Symptoms include redness, itching and pain.

Beryllium: Particulate that becomes lodged under the skin has the potential to induce sensitization and skin lesions.

Cobalt: Prolonged and/or repeated contact may cause dermatitis.

Copper: Particulate may cause a greenish-black skin discoloration.

Nickel: May cause allergic dermatitis. Nickel is a contact allergen and sensitizer.

3.2.4 Eyes

Exposure may result from direct contact with airborne particulate or contact to the eye with contaminated hands or clothing. Damage can result from irritation or mechanical injury to the eyes by particulate.

Copper: Particulate in the eyes may cause discoloration.

3.2.5 Chronic (long-term health effects)

Beryllium: Inhaling particulate containing beryllium may cause a serious, chronic lung disease called chronic beryllium disease (CBD) in some individuals. Over time lung disease can be fatal. Chronic beryllium disease is a hypersensitivity or allergic condition in which the tissues of the lungs become inflamed. This inflammation, sometimes with accompanying fibrosis (scarring), may restrict the exchange of oxygen between the lungs and the bloodstream. Medical science suggests that CBD may be related to genetic factors.

Cobalt: Repeated exposure may cause allergic respiratory reaction (asthma). Chronic inhalation of particulate may lead to restricted pulmonary function and lung fibrosis (scarring). Chronic ingestion may result in heart damage and/or failure, vomiting, convulsions and thyroid enlargement. Repeated exposure may cause sensitization dermatitis.

Copper: Prolonged or repeated exposure to copper can discolor skin and hair and irritate the skin; may cause mild dermatitis, runny nose, and irritation of the mucous membranes. Repeated ingestion may damage the liver and kidneys. Repeated Inhalation can cause chronic respiratory disease.

Nickel: Prolonged exposure to excessive concentrations of particulate may cause chronic pulmonary disorders. Nickel and certain nickel compounds are considered carcinogenic and noted for producing nasal and lung cancer. Prolonged or repeated skin contact may cause sensitization dermatitis and possible destruction and/or ulceration.

3.2.6 Carcinogenic References

Beryllium: The International Agency for Research on Cancer (IARC) lists beryllium as a Group 1 – Known Human Carcinogen. The National Toxicology Program (NTP) lists beryllium as reasonably anticipated to be a human carcinogen. The ACGIH lists beryllium as an A1 – Confirmed Human Carcinogen.

IARC lists beryllium as a known human carcinogen (Group1) and notes that the work environment of workers involved in refining, machining and producing beryllium metal was associated with an increased risk of lung cancer, "the greater excess was in workers hired before 1950 when exposures to beryllium in the work place were relatively uncontrolled and much higher than in subsequent decades"; and "the highest risk for lung cancer being observed among individuals diagnosed with acute beryllium-induced pneumonitis, who represent a group that had the most intense exposure to beryllium." IARC further noted that "Prior to 1950, exposure to beryllium in working environments was usally very high, and concentrations exceeding 1 mg/m3 [1000 micrograms per cubic meter] were not unusual."

Cobalt: The International Agency for Research on Cancer (IARC) lists cobalt as a Group 2B – Possibly Carcinogenic to Humans. ACGIH lists elemental cobalt as an A3 – Animal Carcinogen. OSHA lists cobalt as a possible select carcinogen.

Nickel: The International Agency for Research on Cancer (IARC) lists nickel as a Group 2B – Possibly Carcinogenic to Humans. The National Toxicology Program (NTP) lists nickel as reasonably anticipated to be a human carcinogen. The ACGIH lists elemental nickel as an A5 – Not Suspected as a Human Carcinogen and insoluble nickel compounds as an A1 – Confirmed Human Carcinogen.

Zirconium: The ACGIH list zirconium as an A4 – Not Classifiable as a Human Carcinogen.

3.2.7 Medical Conditions Aggravated by Exposure

Persons with impaired pulmonary function, airway diseases, or conditions such as asthma, emphysema, chronic bronchitis, etc. may incur further impairment if particulate is inhaled. If prior damage or disease to the neurologic (nervous), circulatory, hematologic (blood), or urinary (kidney) systems has occurred, proper screening or examinations should be conducted on individuals who may be exposed to further risk where handling and use of this material may cause exposure.

Beryllium: The effects of chronic beryllium disease on the lungs and heart are additive to the effects of other health conditions.

Copper: Persons with pre-existing skin disorders or impaired liver, kidney, or pulmonary function or pre-existing Wilson's disease may be more susceptible to the effects of this material.

Nickel: Skin contact with some nickel compounds in sensitive individuals may cause dermatitis (nickel itch).

3.3 POTENTIAL ENVIRONMENTAL EFFECTS

See Ecological Information (Section 12)

4. <u>FIRST AID MEASURES</u>

4.1 FIRST AID PROCEDURES

INHALATION: Breathing difficulty caused by inhalation of particulate requires immediate removal to fresh air. If breathing has stopped, perform artificial respiration and obtain medical help.

INGESTION: Induce vomiting immediately as directed by medical personnel. Never give anything by mouth to an unconscious person.

SKIN: Thoroughly wash skin cuts or wounds to remove all particulate debris from the wound. Seek medical attention for wounds that cannot be thoroughly cleansed. Treat skin cuts and wounds with standard first aid practices such as cleansing, disinfecting and covering to prevent wound infection and contamination before continuing work. Obtain medical help for persistent irritation. Material accidentally implanted or lodged under the skin must be removed.

EYES: Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

4.2 NOTE TO PHYSICIANS

Treatment of Chronic Beryllium Disease: There is no known treatment which will cure chronic beryllium disease. Prednisone or other corticosteroids are the most specific treatment currently available. They are directed at suppressing the immunological reaction and can be effective in diminishing signs and symptoms of chronic beryllium disease. In cases where steroid therapy has had only partial or minimal effectiveness, other immunosuppressive agents, such as cyclophosphamide, cyclosporine, or methotrexate, have been used. These latter agents remain investigational. Further, in view of the potential side effects of all the immunosuppressive medications, including steroids such as prednisone, they should be used only under the direct care of a physician. In general, these medications should be reserved for cases with significant symptoms and/or significant loss of lung function. Other symptomatic treatment, such as oxygen, inhaled steroids or bronchodilators, may be prescribed by some physicians and can be effective in selected cases.

The decision about when and with what medication to treat is a judgment situation for individual physicians. For the most part, treatment is reserved for those persons with symptoms and measurable loss of lung function. The value of starting oral steroid treatment, before signs or symptoms are evident, remains a medically unresolved issue.

The effects of continued low exposure to beryllium are unknown for individuals who are sensitized to beryllium or who have a diagnosis of chronic beryllium disease. It is generally recommended that persons who are sensitized to beryllium or who have CBD terminate their occupational exposure to beryllium.

5. FIRE FIGHTING MEASURES

Flash Point	Non-combustible as a solid. No ignition as layer of sub 44 micron particles of copper.
Explosive Limits	Not applicable to solids. No ignition as cloud of sub 44 micron particles of nominal copper.
Extinguishing Media	This material is non-combustible. Use extinguishing media appropriate to the surrounding fire.
Unusual Fire and Explosion Hazards	Do not use water to extinguish fires around operations involving molten metal due to the potential for steam explosions.
Special Fire Fighting Procedures	Pressure-demand self-contained breathing apparatus must be worn by firefighters or any other persons potentially exposed to the metal fumes or dust released during or after a fire.

6. ACCIDENTAL RELEASE MEASURES

6.1 STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED

If this material is a particulate, establish a restricted entry zone based on the severity of the spill. Persons entering the restricted zone must wear adequate respiratory protection and protective clothing appropriate for the severity of the spill (see Section 8). Cleanup spills with a vacuum system utilizing a high efficiency particulate air (HEPA) filtration system followed by wet cleaning methods. Special precautions must be taken when changing filters on HEPA vacuum cleaners used to clean up hazardous materials. Be careful to minimize airborne generation of particulate and avoid contamination of air and water. Depending upon the quantity of material released into the environment, the incident may be required to be reported to the National Response Center at (800) 424-8802 as well as the State Emergency Response Commission and Local Emergency Planning Committee.

7. HANDLING AND STORAGE

7.1 HANDLING

Particulate may enter the body through cuts, abrasions or other wounds on the surface of the skin. Wear gloves when handling parts with loose surface particulate or sharp edges.

7.2 STORAGE

Store in a dry area.

8. EXPOSURE CONTROLS, PERSONAL PROTECTION

8.1 VENTILATION AND ENGINEERING CONTROLS

Whenever possible, the use of local exhaust ventilation or other engineering controls is the preferred method of controlling exposure to airborne particulate. Where utilized, exhaust inlets to the ventilation system must be positioned as close as possible to the source of airborne generation. Avoid disruption of the airflow in the area of a local exhaust inlet by equipment such as a man-cooling fan. Check ventilation equipment regularly to ensure it is functioning properly. Provide training on the use and operation of ventilation to all users. Use qualified professionals to design and install ventilation systems.

8.2 WORK PRACTICES

Develop work practices and procedures that prevent particulate from coming in contact with worker skin, hair, or personal clothing. If work practices and/or procedures are ineffective in controlling airborne exposure or visual particulate from deposition on skin, hair, or clothing, provide appropriate cleaning/washing facilities. Procedures should be written that clearly communicate the facility's requirements for protective clothing and personal hygiene. These clothing and personal hygiene requirements help keep particulate from being spread to non-production areas or from being taken home by the worker. Never use compressed air to clean work clothing or other surfaces.

Fabrication processes may leave a residue of particulate on the surface of parts, products or equipment that could result in employee exposure during subsequent material handling activities. As necessary, clean loose particulate from parts between processing steps. As a standard hygiene practice, wash hands before eating or smoking.

To prevent exposure, remove surface scale or oxidation formed on cast or heat treated products in an adequately ventilated process prior to working the surface.

8.3 WET METHODS

Machining operations are usually performed under a liquid lubricant/coolant flood which assists in reducing airborne particulate. However, the cycling through of machine coolant containing finely divided particulate in suspension can result in the concentration building to a point where the particulate may become airborne during use. Certain processes such as sanding and grinding may require complete hooded containment and local exhaust ventilation. Prevent coolant from splashing onto floor areas, external structures or operators' clothing. Utilize a coolant filtering system to remove particulate from the coolant.

8.4 RESPIRATORY PROTECTION

When airborne exposures exceed or have the potential to exceed the occupational limits shown in Section 8.13, approved respirators must be used as specified by an Industrial Hygienist or other qualified professional. Respirator users must be medically evaluated to determine if they are physically capable of wearing a respirator. Quantitative and/or qualitative fit testing and respirator training must be satisfactorily completed by all personnel prior to respirator use. Users of tight fitting respirators must be clean shaven on those areas of the face where the respirator seal contacts the face. Exposure to unknown concentrations of particulate requires the wearing of a pressure-demand airline respirator or pressure-demand self-contained breathing apparatus (SCBA). Use pressure-demand airline respirators when performing jobs with high potential exposures such as changing filters in a baghouse air cleaning device.

8.5 OTHER PROTECTIVE EQUIPMENT

Protective overgarments or work clothing must be worn by persons who may become contaminated with particulate during activities such as machining, furnace rebuilding, air cleaning equipment filter changes, maintenance, furnace tending, etc. Contaminated work clothing and overgarments must be managed in a controlled manner to prevent secondary exposure to workers of third parties, to prevent the spread of particulate to other areas, and to prevent particulate from being taken home by workers.

8.6 PROTECTIVE GLOVES

Wear gloves to prevent contact with particulate or solutions. Wear gloves to prevent metal cuts and skin abrasions during handling.

8.7 EYE PROTECTION

Wear safety glasses, goggles, face shield, or welder's helmet when risk of eye injury is present, particularly during melting, casting, machining, grinding, welding, powder handling, etc.

8.8 HOUSEKEEPING

Use vacuum and wet cleaning methods for particulate removal from surfaces. Be certain to de-energize electrical systems, as necessary, before beginning wet cleaning. Use vacuum cleaners with high efficiency particulate air (HEPA). Do not use compressed air, brooms, or conventional vacuum cleaners to remove particulate from surfaces as this activity can result in elevated exposures to airborne particulate. Follow the manufacturer's instructions when performing maintenance on HEPA filtered vacuums used to clean hazardous materials.

8.9 MAINTENANCE

During repair or maintenance activities the potential exists for exposures to particulate in excess of the occupational standards. Under these circumstances, protecting workers can require the use of specific work practices or procedures involving the combined use of ventilation, wet and vacuum cleaning methods, respiratory protection, decontamination, special protective clothing, and when necessary, restricted work zones.

8.10 WELDING

In accordance with OSHA regulation 29 CFR 1910.252 welding of materials containing beryllium is regulated as follows: Welding or cutting indoors, outdoors, or in confined spaces involving beryllium containing base or filler metals shall be done using local exhaust ventilation and pressure-demand airline respirators unless atmospheric tests under the most adverse conditions have established that the workers' exposure is within the acceptable concentrations defined by 29 CFR 1910.1000. In all cases, workers in the immediate vicinity of the welding or cutting operations shall be protected as necessary by local exhaust ventilation or airline respirators.

8.11 EXPOSURE CHARACTERIZATION

Determine exposure to airborne particulate by air sampling in the employee breathing zone, work area, and department. Utilize an Industrial Hygienist or other qualified professional to specify the frequency and type of air sampling. Develop and utilize a sampling strategy which identifies the extent of exposure variation and provides statistical confidence in the results. Conduct an exposure risk assessment of processes to determine if conditions or situations exist which dictate the need for additional controls or improved work practices. Make air sample results available to employees.

8.12 MEDICAL SURVEILLANCE

Beryllium: Medical surveillance for beryllium health effects includes (1) skin examination, (2) respiratory history, (3) examination of the lungs, (4) lung function tests (FVC and FEV1), and (5) periodic chest x-ray. In addition, a specialized, specific, immunological blood test, the beryllium blood lymphocyte proliferation test (BLPT), is available to assist in the diagnosis of beryllium related reactions. Individuals who have an abnormal BLPT are normally referred to a lung specialist for additional specific tests to determine if chronic beryllium disease is present. Note: Substantial inter- and intra-laboratory disagreement exists among the laboratories that conduct this test. The BLPT does not at this time meet the criteria for a screening test. Despite its limitations however, the BLPT remains a useful disease surveillance tool.

8.13 RISK FACTORS

Specific genetic factors have been identified and have been shown to increase an individual's susceptibility to CBD. Medical testing is available to detect genetic factors in individuals.

8.14 OCCUPATIONAL EXPOSURE LIMITS

CONSTITUENTS	OSHA*			ACGIH*		NIOSH RTECS NUMBER
	PEL	CEILING	PEAK	TLV	TLV-STEL	
Beryllium	0.002	0.005	0.025	0.002	0.01	DS1750000
Cobalt	0.1	N/A	N/A	0.02	N/A	GF8750000
Copper Dust & Mist	1	N/A	N/A	1	N/A	GL5325000
Copper Fume	0.1	N/A	N/A	0.2	N/A	GL5325000
Nickel	1	N/A	N/A	1.5	N/A	QR5950000
Zirconium	5	N/A	N/A	5	10	ZH7070000

*ALL CONCENTRATIONS ARE IN MILLIGRAMS PER CUBIC METER OF AIR
(at the concentrations noted above, these constituents may not be visible to the human eye)

A leading scientific body recommending occupational standards is the American Conference of Governmental Industrial Hygienists (ACGIH). The ACGIH recommends standards for all listed substances. The ACGIH defines a threshold limit value (standard) as follows: "Threshold Limit Values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness." "Individuals may also be hypersusceptible or otherwise unusually responsive to some industrial chemicals because of genetic factors, age, personal habits (smoking, alcohol, or other drugs), medication, or previous exposures. Such workers may not be adequately protected from adverse health effects from certain chemicals at concentrations at or below the threshold limits."

ACGIH = American Conference of Governmental Industrial Hygienists
OSHA = Occupational Safety and Health Administration
PEL = Eight-Hour Average Permissible Exposure Limit (OSHA)
CEILING = Not To Be Exceeded Except For Peak Limit (OSHA)
PEAK = 30-Minute Maximum Duration Concentration Above Ceiling Limit (OSHA)
TLV = Eight-Hour Average Threshold Limit Value (ACGIH)
TLV-STEL = 15-Minute Short Term Exposure Limit (ACGIH)
CAS = Chemical Abstract Service
NIOSH = National Institute For Occupational Safety and Health
RTECS = Registry of Toxic Effects of Chemical Substances
NA = Not Applicable

Brush Wellman recommends following good industrial hygiene practice which includes reducing airborne exposures to the lowest feasible level for all constituents in this product.

9. PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL PROPERTIES

Boiling Point (°F):	Not Applicable	Radioactivity:	Not Applicable
Evaporation Rate:	Not Applicable	Solubility:	None
Freezing Point (°F):	Not Applicable	Sublimes At (°F):	Not Applicable
Odor:	None	Vapor Density (Air = 1):	Not Applicable
pH:	Not Applicable	Vapor Pressure (mmHg):	Not Applicable
Physical State:	Solid	% Volatiles By Volume:	None

PHYSICAL PROPERTIES

Alloy Number/Product Name	Color	Melting Point (°F)	Density (lb/in3)
10 (C17500)	Copper	1850	0.319
10X, Q-Max (C175000)	Copper	1830	0.311
165 (C17000)	Brass	1600	0.304
170	Gold	1600	0.302
171 (C17450)	Copper	1885-1960	0.323
174 (C17400) (C17410) (C17420)	Copper	1875	0.318
25, 190, 290, (C17200)	Brass	1600	0.302
3 (C17510)	Copper	1900	0.319

10. STABILITY AND REACTIVITY

General Reactivity	The material is stable
Incompatibility (materials to avoid)	Reacts with some acids and caustic solutions to produce hydrogen gas. Hydrogen gas can be an explosion hazard. Powdered aluminum and chlorinated hydrocarbons may react with explosive violence.
Hazardous Decomposition Products	None under normal conditions of use.
Hazardous Polymerization	Will not occur

11. TOXICOLOGICAL INFORMATION

For questions concerning toxicological information, write to: Medical Director, Brush Wellman Inc., 14710 West Portage River South Road, Elmore, Ohio 43416-9502.

12. ECOLOGICAL INFORMATION

This material can be recycled; contact your Sales Representative.

13. DISPOSAL CONSIDERATIONS

13.1 BYPRODUCT RECYCLING

When recycled (used in a process to recover metals), this material is not classified as hazardous waste under federal law. Seal particulate or particulate containing materials inside two plastic bags, place in a DOT approved container, and label appropriately.

13.2 SOLID WASTE MANAGEMENT

When spent products are declared solid wastes (no longer recyclable), they must be labeled, managed and disposed of, in accordance with federal, state and local requirements. This material may contain one of the following metals regulated under RCRA; chromium, or lead. See Section 2 for chemical composition.

14. TRANSPORT INFORMATION

There are no U.S. Department of Transportation hazardous material regulations which apply to the packaging and labeling of this product as shipped by Brush Wellman.

Hazard Communication regulations of the U.S. Occupational Safety and Health Administration require this product be labeled.

15. REGULATORY INFORMATION

15.1. UNITED STATES FEDERAL REGULATIONS

15.1.1 Occupational Safety and Health Administration (OSHA)

Air contaminants, 29 CFR 1910.1000
Hazard Communication Standard, 29 CFR 1910.1200

15.1.2 Environmental Protection Agency (EPA)

AMBIENT AIR EMISSIONS: Foundries melting alloys containing beryllium are subject to the National Emission Standard for Beryllium as promulgated by EPA (40 CFR 61, Subpart C). Facilities machining alloys containing greater than 5% beryllium also are subject to the National Emission Standard for beryllium. The National Emission Standard for beryllium is 0.01 micrograms per cubic meter (30 day average) in ambient air for those production facilities which have been qualified to be regulated through ambient air monitoring. Other facilities must meet a 10 gram per 24-hour total site emission limit. Most process air emission sources will require an air permit from a local and/or state air pollution control agency. The use of air cleaning equipment is recommended to achieve the permissible emission. Provide tempered makeup air to prevent excessive negative pressure in a building. Direct recycling of filtered process exhaust air is not recommended. Locate plant exhausts so as not to re-enter the plant through makeup air or other inlets. Regular maintenance and inspection of air cleaning equipment and monitoring of operating parameters is recommended to ensure system efficiency is maintained.

WASTEWATER: Wastewater regulations can vary considerably. Contact your local and state governments to determine their requirements.

TOXIC SUBSTANCES CONTROL ACT: This material is a mixture. Component(s) of this material is/are listed on the TSCA Chemical Substance Inventory of Existing Chemical Substances

SARA TITLE III REPORTING REQUIREMENTS: On February 16, 1988 the U.S. Environmental Protection Agency (EPA) issued a final rule that implements the requirements of the Superfund Amendments and Reauthorization Act (SARA) Title III, Section 313 (53) Federal Register 4525. Title III is the portion of SARA concerning emergency planning and community right-to-know issues. Section 313 covers annual emission reporting on specific chemicals which are manufactured, processed or used at certain U.S. Industrial facilities.

Brush Wellman products are reportable under the Section 313 category of Compounds and/or Mixtures. These mixtures contain one or more of the following reportable constituents: Beryllium, Cobalt, Copper, and Nickel. The specific chemical makeup, concentration by weight and the Chemical Abstracts Services number for each of our products is provided in Section 2.

You may obtain additional information by calling the EPA SARA Title III Hotline at 1-800-535-0202 (or 703 412 9810).

15.2 STATE REGULATIONS

Beryllium

- Is listed on the following state right to know lists: California, New Jersey, Florida, Pennsylvania, Minnesota and Massachusetts.
- The following statements are made in order to comply with the California State Drinking Water Act - Warning: This product contains BERYLLIUM, a chemical known to the state of California to cause cancer.
- California No Significant Risk Level: CAS# 7440-41-7: No significant risk level = 0.1 ug/day

Cobalt

- Is listed on the following state right to know lists: California, New Jersey, Florida, Pennsylvania, Minnesota, Massachusetts.
- The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act WARNING: This product contains COBALT, a chemical known to the state of California to cause cancer.
- California No Significant Risk Level: Not listed.

Copper

- Is listed on the following state right to know lists: California, New Jersey, Florida, Pennsylvania, Minnesota, Massachusetts. California No Significant Risk Level: Not listed.

Nickel

- Is listed on the following state right to know lists: California, New Jersey, Florida, Pennsylvania, Minnesota, Massachusetts.
- The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act - WARNING: This product contains NICKEL, a chemical known to the state of California to cause cancer.
- California No Significant Risk Level: Not listed.

Zirconium

- Is listed on the following state right to know lists: California, New Jersey, Florida, Pennsylvania, Minnesota, Massachusetts.
- California No Significant Risk Level: Not listed.

15.3 CANADA

Constituent	DSL/NDSL	WHMIS Classification	Ingredient Disclosure List
Beryllium	Yes/No	D2A,D2B	Yes
Cobalt	Yes/No	D2A,D2B	Yes
Copper	Yes/No	D2B	Yes
Nickel	Yes/No	D2A	Yes
Zirconium	Yes/No	D2B	Yes

16. OTHER INFORMATION

Following is the label which accompanies this product during shipment.

A10

Copper Beryllium Wrought Alloy

WARNING

INHALING DUST OR FUMES MAY CAUSE CHRONIC BERYLLIUM DISEASE, A SERIOUS CHRONIC LUNG DISEASE, IN SOME INDIVIDUALS. CANCER HAZARD. OVER TIME, LUNG DISEASE AND CANCER CAN BE FATAL. TARGET ORGAN IS PRIMARILY THE LUNG.

READ THE MATERIAL SAFETY DATA SHEET (MSDS) ON FILE WITH YOUR EMPLOYER BEFORE WORKING WITH THIS MATERIAL.

This product contains beryllium and may contain nickel. Overexposure to beryllium by inhalation may cause chronic beryllium disease, a serious chronic lung disease.

- If processing or recycling produces particulate, use exhaust ventilation or other controls designed to prevent exposure to workers. Examples of such activities include melting, welding, grinding, abrasive sawing, sanding and polishing. Any activity which abrades the surface of this material can generate airborne particulate.
- The Occupational Safety and Health Administration (OSHA) has set mandatory limits on occupational exposures.
- Copper beryllium, in solid form and as contained in finished products presents no special health risks.
- Sold for manufacturing purposes only. This product can be recycled; contact your sales representative.

The Occupational Safety and Health Administration requires employers to provide training in the proper use of this product.

For further information, please telephone or write to: Product Stewardship Department, Brush Wellman Inc., 17876 St. Clair Avenue, Cleveland, Ohio 44110, telephone: (800) 862-4118, www.brushwellman.com. For transportation emergency call Chemtrec at (800) 424-9300. A10

*Label may vary in size

*Label color (light blue edge with black lettering)

This MSDS has been revised following the guidelines outlined in the American National Standard for Hazardous Industrial Chemicals -"Material Safety Data Sheets - Preparation." Z400.1-1998

MSDS Status: Revised Sections 1,2

IMPORTANT: If you have any questions or require additional information regarding the materials described in this Material Safety Data Sheet, please telephone or write to the Product Stewardship Department at the location given on page 1. Additional product safety information, such as Safety Facts, is available from your sales representative or at www.brushwellman.com or www.befacts.com.

Lockheed Martin Space Systems Fed Standard 313D
The intent of this cover sheet is to provide those data directed by Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA

Program: HST/ HRVDM/ HDV

Contract / RFP #: NNG0461779R

LM Subcontractor if applicable: ____________

Sub's MSDS #: ____________

LM MSDS/ CRN #: C 02687

Material Description: Helium gas

Material Supplier: Air Products

Suppliers Part #: **

Suppliers CAGE: **

National Stock #: **

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Title of Spec: ____________

DOT Proper Shipping Name: Helium, compressed

DOT Hazard Class: 2.2

DOT PK Group:
Land: See comments
Air: See comments
Water: See comments

UN/ NA ID #: UN 1046

Comments: Not applicable to this hazard class

** = Not available at time of proposal

C02687

AIR PRODUCTS

Material Safety Data Sheet

Version 1.0
Revision Date 04/07/2004

MSDS Number 300000003826
Print Date 04/14/2004

1. PRODUCT AND COMPANY IDENTIFICATION

Product name	:	Helium
Chemical formula	:	He
Synonyms	:	Helium, Helium gas, Gaseous helium, Balloon gas
Product Use Description	:	Medical Applications
Company		Air Products and Chemicals,Inc 7201 Hamilton Blvd. Allentown, PA 18195-1501
Telephone	:	800-345-3148
Emergency telephone number	:	800-523-9374 USA 01-610-481-7711 International

2. COMPOSITION/INFORMATION ON INGREDIENTS

Components	CAS Number	Concentration (Volume)
Helium	7440-59-7	100 %

Concentration is nominal. For the exact product composition, please refer to Air Products technical specifications.

3. HAZARDS IDENTIFICATION

Emergency Overview

High pressure gas.
Can cause rapid suffocation.
Self contained breathing apparatus (SCBA) may be required.

Potential Health Effects

Inhalation	:	In high concentrations may cause asphyxiation. Asphyxiation may bring about unconsciousness without warning and so rapidly that victim may be unable to protect themselves.
Eye contact	:	No adverse effect.
Skin contact	:	No adverse effect.
Ingestion	:	Ingestion is not considered a potential route of exposure.
Chronic Health Hazard	:	Not applicable.

Exposure Guidelines

Primary Routes of Entry : Inhalation

Target Organs : None known.

Symptoms : Exposure to oxygen deficient atmosphere may cause the following symptoms: Dizziness. Salivation. Nausea. Vomiting. Loss of mobility/consciousness.

Aggravated Medical Condition

None.

Environmental Effects

Not harmful.

4. FIRST AID MEASURES

General advice : Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

Eye contact : Not applicable.

Skin contact Not applicable.

Ingestion Ingestion is not considered a potential route of exposure.

Inhalation Remove to fresh air. If breathing is irregular or stopped, administer artificial respiration. In case of shortness of breath, give oxygen.

5. FIRE-FIGHTING MEASURES

Suitable extinguishing media : All known extinguishing media can be used.

Specific hazards Upon exposure to intense heat or flame, cylinder will vent rapidly and or rupture violently. Product is nonflammable and does not support combustion. Move away from container and cool with water from a protected position. Keep containers and surroundings cool with water spray.

Special protective equipment for fire-fighters : Wear self contained breathing apparatus for fire fighting if necessary.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions : Evacuate personnel to safe areas. Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe. Monitor oxygen level. Ventilate the area.

Environmental precautions : Do not discharge into any place where its accumulation could be dangerous. Prevent further leakage or spillage if safe to do so.

Methods for cleaning up : Ventilate the area.

Additional advice : If possible, stop flow of product. Increase ventilation to the release area and monitor oxygen level. If leak is from cylinder or cylinder valve, call the Air Products emergency telephone number. If the leak is in the user's system, close the cylinder valve, safely vent the pressure, and purge with an inert gas before attempting repairs.

7. HANDLING AND STORAGE

Handling

Protect cylinders from physical damage; do not drag, roll, slide or drop. Do not allow storage area temperature to exceed 50°C (122°F). Only experienced and properly instructed persons should handle compressed gases. Before using the product, determine its identity by reading the label. Know and understand the properties and hazards of the product before use. When doubt exists as to the correct handling procedure for a particular gas, contact the supplier. Do not remove or deface labels provided by the supplier for the identification of the cylinder contents. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use. Use an adjustable strap wrench to remove over-tight or rusted caps. Before connecting the container, check the complete gas system for suitability, particularly for pressure rating and materials. Before connecting the container for use, ensure that back feed from the system into the container is prevented. Ensure the complete gas system is compatible for pressure rating and materials of construction. Ensure the complete gas system has been checked for leaks before use. Employ suitable pressure regulating devices on all containers when the gas is being emitted to systems with lower pressure rating than that of the container. Never insert an object (e.g. wrench, screwdriver, pry bar, etc.) into valve cap openings. Doing so may damage valve, causing a leak to occur. Open valve slowly. If user experiences any difficulty operating cylinder valve discontinue use and contact supplier. Close container valve after each use and when empty, even if still connected to equipment. Never attempt to repair or modify container valves or safety relief devices. Damaged valves should be reported immediately to the supplier. Close valve after each use and when empty. Replace outlet caps or plugs and container caps as soon as container is disconnected from equipment. Do not subject containers to abnormal mechanical shocks which may cause damage to their valve or safety devices. Never attempt to lift a cylinder by its valve protection cap or guard. Do not use containers as rollers or supports or for any other purpose than to contain the gas as supplied. Never strike an arc on a compressed gas cylinder or make a cylinder a part of an electrical circuit. Do not smoke while handling product or cylinders. Never re-compress a gas or a gas mixture without first consulting the supplier. Never attempt to transfer gases from one cylinder/container to another. Always use backflow protective device in piping. When returning cylinder install valve outlet cap or plug leak tight. Never use direct flame or electrical heating devices to raise the pressure of a container. Containers should not be subjected to temperatures above 50°C (122°F). Prolonged periods of cold temperature below -30°C (-20°F) should be avoided.

Storage

Full containers should be stored so that oldest stock is used first. Containers should be stored in a purpose build compound which should be well ventilated, preferably in the open air. Stored containers should be periodically checked for general condition and leakage. Observe all regulations and local requirements regarding storage of containers. Protect containers stored in the open against rusting and extremes of weather. Containers should not be stored in conditions likely to encourage corrosion. Containers should be stored in the vertical position and properly secured to prevent toppling. The container valves should be tightly closed and where appropriate valve outlets should be capped or plugged. Container valve guards or caps should be in place. Keep containers tightly closed in a cool, well-ventilated place. Store containers in location free from fire risk and away from sources of heat and ignition. Full and empty cylinders should be segregated. Do not allow storage temperature to exceed 50°C (122°F). Return empty containers in a timely manner.

Technical measures/Precautions

Containers should be segregated in the storage area according to the various categories (e.g. flammable, toxic, etc.) and in accordance with local regulations. Keep away from combustible material.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Engineering measures

Provide natural or mechanical ventilation to prevent oxygen deficient atmospheres below 19.5% oxygen.

Personal protective equipment

Respiratory protection :	Self contained breathing apparatus (SCBA) or positive pressure airline with mask are to be used in oxygen-deficient atmosphere. Air purifying respirators will not provide protection. Users of breathing apparatus must be trained.
Hand protection :	Sturdy work gloves are recommended for handling cylinders. The breakthrough time of the selected glove(s) must be greater than the intended use period.
Eye protection :	Safety glasses recommended when handling cylinders.
Skin and body protection	Safety shoes are recommended when handling cylinders.
Special instructions for protection and hygiene	: Ensure adequate ventilation, especially in confined areas.
Remarks	: Simple asphyxiant.

9. PHYSICAL AND CHEMICAL PROPERTIES

Form :	Compressed gas.
Color :	Colorless gas
Odor	No odor warning properties.
Molecular Weight	: 4 g/mol
Relative vapor density	: 0.138 (air = 1)
Density	: 0.012 lb/ft3 (0.0002 g/cm3) at 70 °F (21 °C)
Specific Volume	: 96.68 ft3/lb (6.0349 m3/kg) at 70 °F (21 °C)
Boiling point/range	: -452 °F (-268.9 °C)
Critical temperature	: -450 °F (-267.9 °C)
Water solubility :	0.0015 g/l

10. STABILITY AND REACTIVITY

Stability	: Stable under normal conditions.
Hazardous decomposition products	: None.

11. TOXICOLOGICAL INFORMATION

Acute Health Hazard

Ingestion	: No data is available on the product itself.
Inhalation	: No data is available on the product itself.
Skin.	: No data is available on the product itself.

12. ECOLOGICAL INFORMATION

Ecotoxicity effects

Aquatic toxicity	: No data is available on the product itself.
Toxicity to other organisms	: No data available.

Persistence and degradability

Mobility	: No data available.
Bioaccumulation	: No data is available on the product itself.

Further information

This product has no known eco-toxicological effects.

13. DISPOSAL CONSIDERATIONS

Waste from residues / unused products	: Contact supplier if guidance is required. Return unused product in orginal cylinder to supplier.
Contaminated packaging :	Return cylinder to supplier.

14. TRANSPORT INFORMATION

CFR

Proper shipping name	: Helium, compressed
Class	: 2.2
UN/ID No.	: UN1046

IATA

Proper shipping name : Helium, compressed
Class : 2.2
UN/ID No. : UN1046

IMDG

Proper shipping name : HELIUM, COMPRESSED
Class : 2.2
UN/ID No. : UN1046

CTC

Proper shipping name : HELIUM, COMPRESSED
Class : 2.2
UN/ID No. : UN1046

Further Information
Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency.

15. REGULATORY INFORMATION

OSHA Hazard Communication Standard (29 CFR 1910.1200) Hazard Class(es)
Compressed Gas.

Country	Regulatory list	Notification
USA	TSCA	Included on Inventory.
EU	EINECS	Included on Inventory.
Canada	DSL	Included on Inventory.
Australia	AICS	Included on Inventory.
Japan	ENCS	Included on Inventory.
South Korea	ECL	Included on Inventory.
China	SEPA	Included on Inventory.
Philippines	PICCS	Included on Inventory.
USA	TSCA	Included on Inventory.
EU	EINECS	Included on Inventory.
Canada	DSL	Included on Inventory.
Australia	AICS	Included on Inventory.
Japan	ENCS	Included on Inventory.
South Korea	ECL	Included on Inventory.
China	SEPA	Included on Inventory.
Philippines	PICCS	Included on Inventory.

EPA SARA Title III Section 312 (40 CFR 370) Hazard Classification:
No SARA Hazards.

Sudden Release of Pressure Hazard.

US. California Safe Drinking Water & Toxic Enforcement Act (Proposition 65)
This product does not contain any chemicals known to State of California to cause cancer, birth defects or any other harm.

This product does not contain any chemicals known to State of California to cause cancer, birth defects or any other harm.

16. OTHER INFORMATION

Prepared by : Air Products and Chemicals, Inc. Global EH&S Product Safety Department

For additional information, please visit our Product Stewardship web site at http//www.airproducts.com/productstewardship/

Lockheed Martin Space Systems Fed Standard 313D
The intent of this cover sheet is to provide those data directed by Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA

Program: HST/ HRVDM/ HDV

Contract / RFP #: NNG0461779R

LM Subcontractor if applicable:

Sub's MSDS #:

LM MSDS/ CRN #: C 00378

Material Description: Anhydrous Hydrazine

Material Supplier: Arch Chemicals Inc.

Suppliers Part #: **

Suppliers CAGE: **

National Stock #: NSN-9135-01-373-6641 (Bulk) NSN-9135-01-232-1852 (Drum)

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Tittle of Spec:

DOT Proper Shipping Name: Hydrazine, anhydrous

DOT Hazard Class: 8

DOT PK Group:
- Land: I (8,3,6.1 labeling)
- Air: I (8,3,6.1 labeling)
- Water: I (8,3,6.1 labeling)

UN/ NA ID #: UN 2029

Comments:

** = Not available at time of proposal

C00378

ARCH Arch Chemicals, Inc.

MATERIAL SAFETY DATA

FOR ANY EMERGENCY, CALL 24HOURS/ 7 DAYS:	1-800-654-6911
FOR ALL TRANSPORTATION ACCIDENTS, CALL CHEMTREC(R):	1-800-424-9300
FOR ALL MSDS QUESTIONS & REQUESTS, CALL:	1-800-511-MSDS

PRODUCT NAME: ANHYDROUS HYDRAZINE

I. PRODUCT AND COMPANY IDENTIFICATION

REVISION DATE: 07-13-2000
SUPERCEDES: 11-02-1999

MSDS NO: 00094-0008 - 105314
SYNONYMS: None
CHEMICAL FAMILY: Hydrazine
DESCRIPTION / USE: Aerospace fuel component.
FORMULA: N_2H_4

Arch Chemicals, Inc. 501 Merritt 7 PO Box 5204 Norwalk, CT 06856-5204

II. COMPOSITION/INFORMATION ON INGREDIENTS

CAS or CHEMICAL NAME	CAS #	% Range
Hydrazine	302-01-2	99.5 - 100

III. HAZARDS IDENTIFICATION

OSHA Hazard Classification: possible carcinogen, corrosive to eyes, skin and mucous membranes, toxic by ingestion and inhalation, highly toxic by dermal contact, eye and skin hazard, lung, liver, kidney, blood and nervous system toxin, skin sensitizer, combustible

Routes of Entry: Inhalation, skin, eyes, ingestion
Chemical Interactions: No known interactions
Medical Conditions Aggravated: Liver, kidney, blood, respiratory and central nervous system disorders

Human Threshold Response Data
Odor Threshold:
Hydrazine 3.7 ppm
Irritation Threshold: Not established

Hazardous Materials Identification System/National Fire Protection Association Classifications

Hazard Ratings:	Health	Flammability	Reactivity
HMIS	3	3	3
NFPA	3	3	3

Immediate (Acute) Health Effects

Inhalation Toxicity: Toxic by inhalation. This product is rapidly absorbed through the lungs. Immediate and prolonged contact may result in the following: damage to the liver, kidneys and blood with symptoms of vomiting, diarrhea, dizziness, blue coloration to the skin.

Inhalation Irritation: Inhalation of this material may produce severe irritating and/or corrosive effects to the nose, mouth, throat, and respiratory tract. It may cause burns which can result in symptoms which may include coughing, wheezing, choking, shortness of breath, chest pain, and impairment of lung function. Inhalation of high concentrations can also result in permanent lung damage. May cause pulmonary edema (fluid build-up in lungs).

Skin Contact: Dermal exposure can cause severe irritation and/or burns characterized by redness, swelling, and scab formation. Prolonged skin exposure may cause permanent damage. Dermal contact may cause defatting of skin and/or dermatitis.

Skin Absorption: May be fatal or cause severe toxicity if absorbed through the skin. This product is rapidly absorbed through the skin, and may result in the following: damage to the liver, kidneys and blood with symptoms of vomiting, diarrhea, dizziness, blue coloration to skin.

Eye Contact: Severe irritation and/or burns can occur following exposure. Direct contact may cause impairment of vision and corneal damage. Rinsing of the eye should take place immediately.

Ingestion Irritation: Irritation and/or burns can occur to the entire gastrointestinal tract, including the stomach and intestines, characterized by nausea, vomiting, diarrhea, abdominal pain, bleeding, and/or tissue ulceration or perforation.

Ingestion Toxicity: Toxic if swallowed. This product is rapidly absorbed through the lungs. Immediate and prolonged contact may result in the following: damage to the liver, kidneys and blood with symptoms of vomiting, diarrhea, dizziness, blue coloration to the skin.

AcuteTarget Organ Toxicity: This product is corrosive to all tissues contacted and upon inhalation, may cause irritation to mucous membranes and respiratory tract., Lungs, Liver, Kidneys, Central nervous system, Blood

Prolonged (Chronic) Health Effects

Carcinogenicity: This product is considered to be a suspect human carcinogen based on animal data.

Reproductive and Developmental Toxicity: Industrial exposures kept at or below the occupational exposure standard are not expected to pose a reproductive or developmental toxicity hazard. High dose levels of this chemical produced maternal toxicity, and embryolethality and fetal malformations.

Sensitization: May cause allergic skin sensitization in some individuals.
Inhalation: Prolonged or repeated exposure may cause continuous bronchitis.
Eye Contact: Prolonged contact may result in permanent damage.
Skin Contact: Due to the corrosive nature of this product, prolonged or repeated exposure may cause extensive permanent skin damage.
Ingestion: Chronic ingestion of this product may cause severe irritation and possible corrosive effects.

Chronic Target Organ Toxicity: Liver, Lungs, Kidneys, Blood, Central nervous system

Supplemental Health Hazard Information: No additional health information available.

IV. FIRST AID

Inhalation:	IF INHALED: Remove individual to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Call a physician.
Skin Contact:	IF ON SKIN: Immediately flush skin with plenty of water for 15 minutes. If clothing comes in contact with the product, the clothing should be removed immediately and should be laundered before re-use. Call a physician.
Eyes:	IF IN EYES: Immediately flush eyes with plenty of water for at least 15 minutes while holding eyelids apart. Call a physician immediately.
Ingestion:	IF SWALLOWED: Call a physician immediately. DO NOT induce vomiting unless directed to do so by a physician. Never give anything by mouth to an unconscious person.

V. FIRE FIGHTING MEASURES

Flammability Summary (OSHA): Combustible.

Flammable Properties

Flash Point:	38 Deg. C. / 100 Deg. F.
Autoignition Temperature:	Test Method: US Bureau of Mines Bulletin 627: 270 Deg. C. / 518 Deg. F.
Upper Flammable/Explosive Limit, % in air:	100%
Lower Flammable/Explosive Limit, % in air:	4.7%
Fire/Explosion Hazards:	Material may be ignited if preheated to temperatures above the flash point in the presence of a source of ignition. Combustible Liquid. Can form explosive mixtures at temperatures at or above the flash point.
Extinguishing Media:	Water is the preferred extinguishing media as it will dilute the material resulting in a non-flammable mixture. Use alcohol foam, carbon dioxide, or water spray when fighting fires involving this material.
Fire Fighting Instructions:	Use water to cool containers exposed to fire. See Section VI for protective equipment for fire fighting.
Hazardous Combustion Products:	Ammonia, Hydrogen

VI. ACCIDENTAL RELEASE MEASURES

Personal Protection for Emergency Situations:	Response to this material requires the use of a full encapsulated suit and self-contained breathing apparatus (SCBA).
Spill Mitigation Procedures	
Air Release:	Vapors may be suppressed by the use of water fog. Contain all liquid for treatment and/or disposal as a (potential) hazardous waste.
Water Release:	This material is heavier than water. This material is soluble in water. Notify all downstream users of possible contamination. Divert water flow around spill if possible and safe to do so.
Land Release:	Dike spill area as soon as possible. Dilute the spilled material to about 10% with water. Neutralize the diluted material by slowly adding a 5-8% calcium hypochlorite solution until all the diluted material has been reacted. DO NOT ADD DRY CALCIUM HYPOCHLORITE TO THE SPILL AS A VIOLENT REACTION MAY RESULT. If unable to remove as a liquid, absorb in clay, sand or a commercial absorbent. Do not place spill materials back in their original containers. This substance cannot be removed from leather. All contaminated leather articles should be rinsed with water and discarded.

Additional Spill Information:	Remove all sources of ignition. If this material is released into a work area, evacuate the area immediately. Hazardous concentrations in air may be found in local spill area and immediately downwind. Utilize emergency response personal protection equipment prior to the start of any response. Stop source of spill as soon as possible and notify appropriate personnel. This material may be neutralized for disposal; you are requested to contract Arch Chemicals at 1- 800-654-6911 before beginning any such procedure. Containerize and label properly and remove to a secure location for proper disposal. Decontaminate all clothing and the spill area using a detergent and flush with large amounts of water.

VII. HANDLING AND STORAGE

Handling:	Avoid contact with material, avoid breathing vapors, use only in a well ventilated area, use bonding and grounding when transferring quantities of material. Do not take internally. Avoid contact with skin, eyes and clothing. Upon contact with skin or eyes, wash off with water.
Storage:	Store in a cool dry ventilated location, away from sources of ignition or other incompatible conditions and chemicals. Keep container(s) closed. Avoid direct exposure to sunlight or ultraviolet (UV) light sources. Keep under a nitrogen blanket.
Shelf Life Limitations:	5 Years if not opened and exposed to the atmosphere. Material older than five years should be retested before use.
Incompatible Materials for Storage:	strong oxidizing agents, metal oxides, organic materials with high surface area such as rags, cotton waste, sawdust, etc., peroxides
Do Not Store At temperatures Above:	51 Deg. C. 124 Deg. F.

VIII. EXPOSURE CONTROLS / PERSONAL PROTECTION

Ventilation:	Local exhaust ventilation or other engineering controls are imperative when handling or using this product to keep employee exposure to airborne contaminants below the exposure limit. Use explosion-proof ventilation equipment when handling this product.

Protective Equipment for Routine Use of Product

Respiratory Protection:	Wear a NIOSH approved respirator if any exposure occurs.
Respirator Type(s):	NIOSH approved full-face positive pressure supplied-air respirator
Skin:	A full impervious suit is recommended if exposure is possible to a large portion of the body. Wear impervious gloves, boots and apron to avoid skin contact.
Eyes:	Use chemical goggles and a faceshield.
Protective Clothing Type:	Butyl rubber
Other PPE:	An eye wash and safety shower should be provided in the immediate work area.

Exposure Limit Data

CHEMICAL NAME	CAS #	OSHA PEL / STEL	ACGIH LIMITS
Hydrazine	302-01-2	1 ppm TWA; 1.3 mg/m3 TWA prevent or reduce skin absorption	skin - potential for cutaneous absorption 0.01 ppm TWA

CHEMICAL NAME NIOSH Immediately Dangerous to Life or Health:

Hydrazine	50 ppm (not considering carcinogenic effects)

IX. PHYSICAL DATA

Physical State:	liquid
Color:	colorless
Odor	Ammonia
Molecular Weight:	32.04
pH	10.1 - 10.7 (1% solution in neutral distilled water)
Octanol/Water Coeff:	No data
Solubility in Water:	Miscible
Bulk Density:	1.004 g/cc
Specific Gravity:	1.004
Vapor Density:	1.1 (air=1)
Vapor Pressure:	(@ 25 Deg. C) 14.9 mmHg
Evaporation Rate:	No data
Volatiles, % by vol.:	100 %
Boiling Point:	113.5 Deg. C. / 236 Deg. F.
Freezing Point:	1.5 Deg. C. / 35 Deg. F.

X. STABILITY AND REACTIVITY

Stability and Reactivity Summary:	May become unstable at elevated temperatures and/or pressure. Not sensitive to mechanical shock.
Reactive Properties:	Strong reducing agent, Corrosive
Hazardous Polymerization:	Will not occur
Conditions to Avoid:	Temperatures above the flash point in combination with sparks, open flames, or other sources of ignition. Avoid contact with organic materials.
Chemical Incompatibility:	strong oxidizing agents, peroxides, nitrogen tetroxide, fuming nitric acid, fluorine, halogen fluorides, metal oxides such as those of iron, copper, lead, manganese, and molybdenum
Packaging Incompatibility:	Package only in Teflon(R) high density polyethylene or 304L or 347 stainless steels containing less than 0.5% molybdenum.
Hazardous Decomposition Products:	ammonia, hydrogen
Decomposition Temperature:	270 Deg. C. 518 Deg. F.
Product May Be Unstable At Temperatures Above:	270 Deg. C. 518 Deg. F.

XI. TOXICOLOGICAL INFORMATION

Animal

Oral LD50 value:	Oral LD50 Rat 60 mg/kg
Dermal LD50 value:	Dermal LD50 Rabbit 93 mg/kg
Inhalation LC50 value:	Inhalation LC50 (4h) Rat 570 ppm
Skin Irritation:	This material is expected to be corrosive.
Eye Irritation:	This material is expected to cause irreversible effects to the cornea with impairment of vision or corrosion to the eyes.
Skin Sensitization:	Produces allergic skin response in Human Repeat Insult Patch test.
Acute Toxicity:	Damage occurs to liver, kidney, central nervous system, blood and lungs.
Reproductive and Developmental Toxicity:	Industrial exposures kept at or below occupational exposures standards should not pose a reproductive or developmental toxicity hazard. High dose levels of this chemical produced maternal toxicity, and embryolethality, and fetal

	malformations.
Mutagenicity:	This product has been tested and was found to be mutagenic.
Carcinogenicity:	This product is considered to be a suspect human carcinogen based on animal data.

XII. ECOLOGICAL INFORMATION

Overview: Moderate ecological hazard. Harmful to fish and other water organisms.

Ecological Toxicity Values:

Hydrazine
Bluegill (Lepomis macrochirus), 96 hr. LC50: 1.08 mg/l (static).
The No Observable Effect Concentration (NOEC): 0.43 mg/l.
Channel Catfish (Ictalurus punctatus rafinesque), 96 hr. LC50: 1 mg/l (static).
Rainbow trout (Salmo gairdneri), 76 hr. LC50: 6 mg/L
Fatal within 1 hour at: 146 mg/l.
Fathead minnow (Pimephales promelas), 96 hr. LC50: 5.98 mg/l (flow-through).
Water flea (Daphnia magna), 24 hr. EC50: 2.3 mg/l.
Green algae (Selenastrum capricornutum), 72 hr. EC50: 0.0061 mg/l.

XIII. DISPOSAL CONSIDERATIONS

CARE MUST BE TAKEN TO PREVENT ENVIRONMENTAL CONTAMINATION FROM THE USE OF THIS MATERIAL. THE USER OF THIS MATERIAL HAS THE RESPONSIBILITY TO DISPOSE OF UNUSED MATERIAL, RESIDUES AND CONTAINERS IN COMPLICANCE WITH ALL RELEVANT LOCAL, STATE AND FEDERAL LAWS AND REGULATIONS REGARDING TREATMENT, STORAGE AND DISPOSAL FOR HAZARDOUS AND NONHAZARDOUS WASTES.

Waste Disposal Summary:	Spent or discarded material is a hazardous waste. If this product becomes a waste, it will be a hazardous waste which is subject to the Land Disposal restrictions under 40 CFR 268 and must be managed accordingly. As a hazardous liquid waste, it must be disposed of in accordance with local, state and federal regulations in a permitted hazardous waste treatment, storage and disposal facility by incineration.
Potential US EPA Waste Codes:	U133
Disposal Methods:	Dispose of by incineration following Federal, State, Local, or Provincial regulations.

Components subject to land ban restrictions: No components subject to land band restrictions.

XIV. TRANSPORTATION INFORMATION

THIS MATERIAL IS REGULATED AS A DOT HAZARDOUS MATERIAL.
DOT Description (49 CFR

Land (U.S. DOT):	Hydrazine, anhydrous , 8 , UN 2029 , PG I , TOXIC.
Air (IATA/ICAO):	Hydrazine, anhydrous, 8, UN 2029, PG I, 3 and 6.1.
Water (IMO):	Hydrazine, anhydrous, 8, UN 2029, PG I, 3.1 and 6.1, (Flash point = 38 Deg. C).

Hazard Label/Placard: (Primary) CORROSIVE
(Subsidiary) FLAMMABLE LIQUID , TOXIC

Reportable Quantity (49 CFR 172.101; Appendix):
Hydrazine final RQ = 1 pound (0.454 kg); also listed as Diamine

Special Comments: FORBIDDEN ON PASSENGER AIRCRAFT

Emergency Response Guide Number: 132

XV. REGULATORY INFORMATION

UNITED STATES:

Toxic Substances Control Act (TSCA): This substance is listed on the TSCA Inventory of Existing Chemical Substances.

Pesticide acceptance indication: US EPA Registration Number: Not applicable

Superfund Amendments and Reauthorization Act (SARA) Title III:

Hazard Categories Sections 311/312 (40 CFR 370.2):

Health: Acute and Chronic

Physical: Fire

Emergency Planning & Community Right to Know (40 CFR 355, App. A):

Extremely Hazardous Substance Section 302 - Threshold Planning Quantity:

Hydrazine TPQ = 1000 pounds; RQ = 1 pound

Reportable Quantity (40 CFR 302.4):

Hydrazine final RQ = 1 pound (0.454 kg)

Supplier Notification Requirements (40 CFR 372.45), 313 Reportable Components

Hydrazine form R reporting required for 0.1% de minimis concentration

Clean Air Act Toxic ARP Section 112r Hydrazine

State Right-to-Know Regulations Status of Ingredients

Pennsylvania:	Hydrazine
New Jersey:	Hydrazine
Massachusetts:	Hydrazine

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT OF 1986 - Proposition 65: "WARNING: This product contains a chemical(s) known to the State of California to cause cancer and/or birth defects or other reproductive harm."

CAS or CHEMICAL NAME	CAS #	% Range	
Hydrazine	302-01-2	99.5 - 100	carcinogen; initial date 1/1/88

XVI. ADDITIONAL INFORMATION

MSDS REVISION STATUS: Revised to meet the ANSI standard of 16 sections.

MAJOR REFERENCES:

1. Roe, F.J.C. 1977. Clinical and Epidemiological Studies on Men Exposed to Hydrazine in the Course of its Manufacture or Use. Wimbledon, London, England.
2. Haun, C. C., and E. R. Kinkead. January 1975. Chronic Inhalation Toxicity of Hydrazine. University of California, Irvine, Toxic Hazards Research Unit, Dayton, Ohio.
3. Mac Ewen, J.D., et al. June 1981. Chronic Inhalation Toxicity of Hydrazine: Oncogenic Effects. Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

4. McKee, J. E., and H. W. Wolf, Eds. 1963. Water Quality Criteria. Publication No. 3-A, The Resources Agency of California, State Water Resources Control Board.
5. Sotaniemi, E., et al. 1971. Hydrazine Toxicity in the Human. Report of a Fatal Case. Annals of Clinical Research 3:30-33.
6. Vernot, E. H., et al. 1985. Long-Term Inhalation Toxicity of Hydrazine. Fundamental and Applied Toxicology, 5, 1050-1064.
7. Lee, S. H. and H. Aleyassine. November 1970. Hydrazine Toxicity in Pregnant Rats. Arch. Environ. Health. Vol. 21.
8. Wald, N., et al. 1984. Occupational exposure to hydrazine and subsequent risk of cancer. British Journal of Industrial Medicine. 41: 31-34.
9. Lyng, R. D., et al. March 1980. Effects of Hydrazine on Pregnant ICR Mice. Air Force Aerospace Medical Research Laboratory, Wright- Patterson Air Force Base, Ohio 45433.
10. Keller, W. C., et al. August 1982. Evaluation of the Embryotoxicity of Hydrazine in Rats. Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433.
11. Toth, B. 1988. Toxicities of Hydrazines: A Review. In Vivo. 2:209-242.
12. United Nations Environment Programme, International Labour Organisation, and World Health Organization. 1987. Environmental Health Criteria 68. World Health Organization.
13. Report on Acute Toxicity of SCAV-OX to Rainbow Trout (Salmo gairdneri), EG&G Bionomics Aquatic Toxicity Laboratory, Wareham, MA. Report No. BW-80-9-738, September 1980.
14. Fisher, J.W., Harrah, C.B. and Berry, W.D. 1980. Acute Toxicity to Bluegills and Sublethal Effects on Dorsal Light Response and Agression. Trans. Am. Fish Soc., 109, 304-309.
15. Bringmann, G. 1982. Results of Toxic Action of Water Pollutants on Daphnia magna Straus Tested by an Improved Standardized Procedure. Z. Wasser Abwasser Forsch., 15, 1-6.
16. United States Air Force Military Specification Number MIL-P-87930.
17. CAS ONLINE (R) - FILE CA, Chemical Asbtracts Service, Columbus, OH.
18. CAS ONLINE - FILE REG, Chemical Abstracts Service, Columbus, OH.
19. Sundstrand Aviation Product Bulletin PB-676A, "Sundstrand Monofuel Power Systems," Sundstrand Corp., Rockville, IL.
20. H.W. Schiessl, "Hydrazine and It's Derivatives," in Kirk-Othmer Encyclopedia of Chemical Technology, 3rd Ed., Mark et al Eds., John Wiley and Sons, New York, NY, 1980.
21. Olin Product Data, Code 731009R2, "Hydrazine, Storage & Handling of Aqueous Solutions", Olin Corporation, Stamford, CT., c1982.
22. E.W. Schmidt, Hydrazine and It's Derivatives, John Wiley and Sons, New York, NY, 1984.
23. Sundstrand Aviation Product Bulletin PB-676A, "Sundstrand Monofuel Power Systems," Sundstrand Corp., Rockford, IL.
24. Fisher, J.W., Myers, D.S., and Meyers, M.L. 1980. The Effects of Selected Hydrazines Upon Fish and Invertebrates. Tech. Rep. Aerosp. Med. Res. Lab. Govt. Rep. Announce. Index, 8014.
26. Velte, J.S. 1984. Acute Toxicity of Hydrazine Hydrate to the Fathead Minnow (Pimephales promelas) and Daphnid (Daphnia pulex). Bull. Environ. Contam. Toxicol., 33, 598-604.
27. Harrah, C.B. 1977. Biological Effects of Aqueous Hydrazine. Proc. Conf. Environ. Chem. Hydrazine Fuels, Tyndall AFB, FL, Air Force Technical Report CEEDO-TR-78-14.

Additional references available upon request.

Lockheed Martin Space Systems Fed Standard 313D

The intent of this cover sheet is to provide those data directed by Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA

Program: HST/ HRVDM/ HDV

Contract / RFP #: NNG0461779R

LM Subcontractor if applicable:

Sub's MSDS #:

LM MSDS/ CRN #: Z 24492

Material Description: Explosive power device (NASA Standard Initiators)

Material Supplier: Hi-Shear Technology

Suppliers Part #: **

Suppliers CAGE: **

National Stock #: **

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Title of Spec:

DOT Proper Shipping Name: Cartridges, power device

DOT Hazard Class: 1.4 C

DOT PK Group		
	Land	II (1.4C labeling)
	Air	II (1.4C labeling)
	Water	II (1.4C labeling)

UN/ NA ID #: UN 0276

Comments:

** = Not available at time of proposal

Z24492

Material Safety Data Sheet
May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY (As Used on Label and List)

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name: Hi-Shear Technology Corp.	Emergency Telephone Number: (310) 784-2100
Address (Number, Street, City, State, and ZIP Code): 24225 Garnier Street	Telephone Number for Information: (310) 784-2100
Torrance, CA 90505	Date Prepared
	Signature of Preparer (optional)

Section II — Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% (optional)
114 mg Zirconium/Potassium Perchlorate Formulation Graphite				
33 mg Hi-Temp Hercules Powder				

The above ingredidents are contained in Hi-Shear Initiator NSI Booster Module 9391926 (PC154-2) and the unit is hermetically sealed. No hazard exists in the 'as-built' condition unless exposed to +500°F for an extended period of time.

Section III — Physical/Chemical Characteristics

Boiling Point	N/A	Specific Gravity (H_2O = 1)	2.6
Vapor Pressure (mm Hg.)	Not measureable up to 500°F	Melting Point	N/A
Vapor Density (AIR = 1)	N/A	Evaporation Rate (Butyl Acetate = 1)	N/A

Solubility in Water: very slight

Appearance and Odor: Black

Section IV — Fire and Explosion Hazard Data

Flash Point (Method Used): N/A	Flammable Limits: Greater than +500°F	LEL: N/A	UEL: N/A

Extinguishing Media: Water

Special Fire Fighting Procedures: None required.

Unusual Fire and Explosion Hazards: If Initiators are exposed to fire, units will fire causing a flame output of approximately one (1) foot in length.

Section V — Reactivity Data

Stability Very Stable	Unstable		Conditions to Avoid Temperatures exceeding +500°F
	Stable	X	

Incompatibility (Materials to Avoid)
Strong Acids

Hazardous Decomposition or Byproducts
N/A

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur	X	

Section VI — Health Hazard Data

Route(s) of Entry:	Inhalation?	Skin?	Ingestion?
	No	No	No

Health Hazards (Acute and Chronic)
No hazard unless fired in unprotected environment-duration of flame and gasses is less than one (1) second.

Carcinogenicity:	NTP?	IARC Monographs?	OSHA Regulated?

Inadequate data

Signs and Symptoms of Exposure
None - in 'as-built' condition

Medical Conditions Generally Aggravated by Exposure
None - in 'as-built' condition

Emergency and First Aid Procedures
Normal burn treatment if exposed to flame.

Section VII — Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled
N/A

Waste Disposal Method
N/A

Precautions to Be Taken in Handling and Storing
Do not expose to temperatures exceeding 300°F

Other Precautions
None

Section VIII — Control Measures

Respiratory Protection (Specify Type)
None

Ventilation Nothing Special	Local Exhaust	N/A	Special	N/A
	Mechanical (General)	N/A	Other	N/A

Protective Gloves	Eye Protection
N/A	Safety Glasses

Other Protective Clothing or Equipment
N/A

Work/Hygienic Practices
N/A

Lockheed Martin Space Systems Fed Standard 313D

The intent of this cover sheet is to provide those data directed by Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA

Program: HST/ HRVDM/ HDV

Contract / RFP #: NNG0461779R

LM Subcontractor if applicable:

Sub's MSDS #:

LM MSDS/ CRN #: Z 24866

Material Description: Explosive power device (Pyro Valve 1/2" 3/8")

Material Supplier: Conax Florida Corporation

Suppliers Part #: **

Suppliers CAGE: **

National Stock #: **

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Title of Spec:

DOT Proper Shipping Name: Cartridges, power device

DOT Hazard Class: 1.4 B

DOT PK Group:

Land	II (1.4C labeling)
Air	II (1.4C labeling)
Water	II (1.4C labeling)

UN/ NA ID #: UN 0323

Comments:

** = Not available at time of proposal

MATERIAL SAFETY DATA SHEET

No. 45-R0338

SECTION I

MANUFACTURER'S NAME AND FSCM (Federal Supply Code for Manufacturers): Conax Florida Corporation 62323	EMERGENCY PHONE NO.: 813-345-8000
ADDRESS (Number, Street, City, State, and ZIP Code): 2801 75th Street North, St. Petersburg, FL 33710	Z23508
CHEMICAL NAME AND SYNONYMS: ——	TRADE NAME AND SYNONYMS: Valve Assembly Normally Closed
CHEMICAL FAMILY: ——	FORMULA: Conax P/N 1832-202
FEDERAL STOCK NUMBER (FSN):	GROSS WEIGHT (LBS):
OUTSIDE PACKAGE DIMENSIONS (Inches):	

MIL-STD-1341/NATIONAL FIRE PROTECTION ASSOCIATION 378 (704) SIGNAL
FLAMMABILITY 2 HEALTH 1 REACTIVITY 1 SPECIFIC HAZARD N/A

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, AND SOLVENTS	%	THRESHOLD LIMIT VALUE (Units)	ALLOYS AND METALLIC COATINGS	%	THRESHOLD LIMIT VALUE (Units)
PIGMENTS		N/A	BASE METAL		N/A
CATALYST		N/A	ALLOYS		N/A
VEHICLE		N/A	METALLIC COATINGS		N/A
SOLVENTS		N/A	FILLER METAL PLUS COATING OR CORE FLUX		N/A
ADDITIVES		N/A	OTHERS		
OTHERS					

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	THRESHOLD LIMIT VALUE (Units)
100 mg. Titanium Hydride Potassium Perchlorate		

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)	N/A	SPECIFIC GRAVITY (H_2O=1)	N/A
VAPOR PRESSURE (mm Hg.)	N/A	PERCENT VOLATILE BY VOLUME (%)	N/A
VAPOR DENSITY (AIR=1)	N/A	EVAPORATION RATE (=1)	
SOLUBILITY IN WATER	N/A		
APPEARANCE AND ODOR			

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used): ——	FLAMMABLE LIMITS	LOWER EXPLOSIVE LIMIT	UPPER EXPLOSIVE LIMIT

EXTINGUISHING MEDIA: ——

SPECIAL FIRE FIGHTING PROCEDURES: USE NORMAL PRECAUTIONS AS IN APPROACHING ANY FIRE. REMOVE FROM HEAT IMMEDIATELY.

UNUSUAL FIRE AND EXPLOSION HAZARDS:

DD FORM 1 JUN 71 1813

SECTION V · HEALTH HAZARD DATA	[illegible]	N/A
	EFFECTS OF OVEREXPOSURE	—
	EMERGENCY AND FIRST AID PROCEDURES	STANDARD MEDICAL TREATMENT
SECTION VI REACTIVITY DATA	STABILITY — UNSTABLE	
	STABILITY — STABLE	X
	CONDITIONS TO AVOID	ELEVATED TEMPERATURES
	INCOMPATABILITY (Materials to avoid)	
	HAZARDOUS DECOMPOSITION PRODUCTS	
	HAZARDOUS POLYMERIZATION — MAY OCCUR	
	HAZARDOUS POLYMERIZATION — WILL NOT OCCUR	
	CONDITIONS TO AVOID	
SECTION VII SPILL OR LEAK PROCEDURES	STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED	N/A
	WASTE DISPOSAL METHOD	N/A
SECTION VIII · SPECIAL PROTECTION INFORMATION	RESPIRATORY PROTECTION (Specify type)	———
	VENTILATION	NONE
	LOCAL EXHAUST	———
	MECHANICAL (General)	———
	SPECIAL	———
	OTHER	———
	PROTECTIVE GLOVES	GOOD PRACTICE
	EYE PROTECTION	GOOD PRACTICE
	OTHER PROTECTIVE EQUIPMENT	NONE
SECTION IX SPECIAL PRECAUTIONS	PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING	UNITS ARE COMPLETELY SELF CONTAINED AND PRESENT NO DANGER UNLESS IMPROPERLY DISASSEMBLED. STORE IN COOL DRY AREAS.
	OTHER PRECAUTIONS	
SECTION X TRANS. DATA	PROPER SHIPPING (Accepted) NAME	Cartridges, power device, UN0276
	DOT CLASSIFICATION	1.4C
	DOT LABEL	1.4C
	DOT MARKING	1.4C
	EMERGENCY ACCIDENT PRECAUTIONS AND PROCEDURES	REMOVE FROM HEAT
	DOT PLACARD	———
	PRECAUTIONS TO BE TAKEN IN TRANSPORTATION	AVOID ELEVATED TEMPERATURES

U.S. GOVERNMENT PRINTING OFFICE: [illegible]

MATERIAL SAFETY DATA SHEET

OMB Approval No. 45-R0332

SECTION I

MANUFACTURER'S NAME AND FSCM (Federal Supply Code for Manufacturers)	Conax Florida Corporation 62523
EMERGENCY PHONE NO.	813-345-8000
ADDRESS (Number, Street, City, State, and ZIP Code)	2801 75th Street North, St. Petersburg, FL 33710
	Z24866
CHEMICAL NAME AND SYNONYMS	
TRADE NAME AND SYNONYMS	Valve Assembly Normally Closed
CHEMICAL FAMILY	
FORMULA	Conax P/N 1832-204
FEDERAL STOCK NUMBER (FSN)	
GROSS WEIGHT (LBS)	
OUTSIDE PACKAGE DIMENSIONS (Inches)	

MIL-STD-1341/NATIONAL FIRE PROTECTION ASSOCIATION STD 704M SIGNAL

FLAMMABILITY 2 HEALTH 1 REACTIVITY 1 SPECIFIC HAZARD N/A

SECTION II - HAZARDOUS INGREDIENTS

PAINTS, PRESERVATIVES, AND SOLVENTS	%	THRESHOLD LIMIT VALUE (Units)	ALLOYS AND METALLIC COATINGS	%	THRESHOLD LIMIT VALUE (Units)
PIGMENTS		N/A	BASE METAL		N/A
CATALYST		N/A	ALLOYS		N/A
VEHICLE		N/A	METALLIC COATINGS		N/A
SOLVENTS		N/A	FILLER METAL PLUS COATING OR CORE FLUX		N/A
ADDITIVES		N/A	OTHERS		
OTHERS					

HAZARDOUS MIXTURES OF OTHER LIQUIDS, SOLIDS, OR GASES	%	THRESHOLD LIMIT VALUE (Units)
120 mg. Titanium Hydride Potassium Perchlorate		

SECTION III - PHYSICAL DATA

BOILING POINT (°F.)	N/A	SPECIFIC GRAVITY ($H_2O=1$)	N/A
VAPOR PRESSURE (mm Hg.)	N/A	PERCENT VOLATILE BY VOLUME (%)	N/A
VAPOR DENSITY (AIR = 1)	N/A	EVAPORATION RATE (= 1)	
SOLUBILITY IN WATER	N/A		
APPEARANCE AND ODOR			

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used)		FLAMMABLE LIMITS	LOWER EXPLOSIVE LIMIT	UPPER EXPLOSIVE LIMIT

EXTINGUISHING MEDIA

SPECIAL FIRE FIGHTING PROCEDURES

USE NORMAL PRECAUTIONS AS IN APPROACHING ANY FIRE. REMOVE FROM HEAT IMMEDIATELY.

UNUSUAL FIRE AND EXPLOSION HAZARDS

DD FORM 1 JUN 71 1813

SECTION V HEALTH HAZARD DATA

N/A

EFFECTS OF OVEREXPOSURE

–

EMERGENCY AND FIRST AID PROCEDURES

STANDARD MEDICAL TREATMENT

SECTION VI REACTIVITY DATA

STABILITY			CONDITIONS TO AVOID
	UNSTABLE		
	STABLE	X	ELEVATED TEMPERATURES

INCOMPATABILITY (Materials to avoid)

–

HAZARDOUS DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERIZATION			CONDITIONS TO AVOID
	MAY OCCUR		
	WILL NOT OCCUR		

SECTION VII SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

N/A

WASTE DISPOSAL METHOD

N/A

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (Specify type)

VENTILATION	LOCAL EXHAUST	SPECIAL
NONE	MECHANICAL (General)	OTHER

PROTECTIVE GLOVES	EYE PROTECTION
GOOD PRACTICE	GOOD PRACTICE

OTHER PROTECTIVE EQUIPMENT

NONE

SECTION IX SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

UNITS ARE COMPLETELY SELF CONTAINED AND PRESENT NO DANGER UNLESS IMPROPERLY DISASSEMBLED. STORE IN COOL DRY AREAS.

OTHER PRECAUTIONS

SECTION X TRANS. DATA

PROPER SHIPPING (Hazardous) NAME		DOT CLASSIFICATION
Cartridges, power device, UN0276		1.4C

DOT LABEL	DOT MARKING	EMERGENCY ACCIDENT PRECAUTIONS AND PROCEDURES
1.4C	1.4C	REMOVE FROM HEAT

DOT PLACARD	PRECAUTIONS TO BE TAKEN IN TRANSPORTATION
————	AVOID ELEVATED TEMPERATURES

U.S. GOVERNMENT PRINTING OFFICE : [illegible]

Material Safety Data Sheet — **MSDS-001**
May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.

U.S. Department of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY (As Used on Label and List)
LITHIUM - ION CELLS

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name Yardney Technical Products, Inc.	*Emergency Telephone Number* (800) 255-3924
Address (Number, Street, City, State, and Zip Code) 82 Mechanic Street	*Telephone Number for Information* 860-599-1100
Pawcatuck, CT 06379	*Date Prepared* 3/12/2002
	Signature of Preparer (optional)

Section II - Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% (optional)
Contains one or more of the following:				
Carbonic Acid, Ethyl Methyl Ester		RTECS#	NA	
Diethyl Carbonate		RTECS#	FF9800000	
Dimethyl Carbonate		RTECS#	FG0450000	
Carbonic Acid, Cyclic Ethylene Ester		RTECS#	FF9550000	
Phosphate (1-), Hexafluoro-, Lithium; $LiPF_6$		RTECS#	NA	
Lithium Tetrafluoroborate; $LiBF_4$				
Lithiated Nickel Oxide Based Components (Suspected Carcinogens)				

Section III - Physical/Chemical Characteristics

Boiling Point	N/A	*Specific Gravity (H2O = 1)*	N/A
Vapor Pressure (mm Hg.)	N/A	*Melting Point*	N/A
Vapor Density (AIR = 1)	N/A	*Evaporation Rate (Butyl Acetate = 1)*	N/A

Solubility in Water
N/A

Appearance and Odor
Hermetically sealed prismatic cell. No odor

Section IV - Fire and Explosion Hazard Data

Flash Point (Method Used)	*Flammable Limits*	*LEL*	*UEL*
N/A	N/A	N/A	N/A

Extinguishing Media
Dry chemical, CO2, water spray or alcohol resistant foam.

Special Fire Fighting Procedures
Use self-contained breathing apparatus.

Unusual Fire and Explosion Hazards
When product is burned, it will emit flouride fumes.
Explosion could result in cases of extreme overcharge.

(Reproduce locally) OSHA 174, Sept. 1985

Lockheed Martin Space Systems Fed Standard 313D
The intent of this cover sheet is to provide those data directed by Fed Standard 313D, which exceed FED OSHA Requirements.

LM Customer: NASA

Program: HRVDM/ HDV

Contract/ RFP#: NNG0461779R

LM Subcontractor if applicable: N/ A

Sub's MSDS #: N/ A

LM MSDS/ CRN #: Z 25401

Material Description: Lithium-ion cells

Material Supplier: Yardney Technical Products, Inc.

Suppliers Part #: **

Suppliers CAGE: 87362

National Stock #: **

Local Stock: **

Federal Supply Schedule #: **

Special Item #: **

Activity Control #: **

Specification #: **

Title of Spec: **

DOT Proper Shipping Name: Lithium Battery

DOT Hazard Class: 9

DOT PK Group:
- Land: II (9 labeling)
- Air: II (9 labeling)
- Water: II (9 labeling)

UN/ NA ID #: UN3090

Comments:

** = Not available at time of proposal

Section V - Reactivity Data

Stability	*Unstable*		*Conditions to Avoid* DO NOT PUNCTURE OR SHORT CIRCUIT, DO NOT MECHANICALLY
	Stable	X	ABUSE; DO NOT OVERCHARGE OR OVERDISCHARGE

Incompatibility (Materials to Avoid)
NONE

Hazardous Decomposition or Byproducts
NONE IN NORMAL CONDITIONS OF USE & SERVICE

Hazardous Polymerization	*May Occur*		*Conditions to Avoid* DO NOT OVERHEAT. DO NOT EXCEED 50°C.
	Will Not Occur X		

Section VI - Health Hazard Data

Route(s) of Entry:	*Inhalation?*	*Skin?*	*Ingestion?*
	N/A	N/A	N/A

Health Hazards (Acute and Chronic)
NONE IN NORMAL CONDITIONS OF USE & SERVICE
Electrolyte is corrosive. Causes chemical burns on contact with skin. Inhalation of fine mist or vapors are irritating to the respiratory system.

Carcinogenicity:	*NTP?*	*IARC Monographs?*	*OSHA Regulated?*
	"N/A	N/A	NO

Signs and Symptoms of Exposure
NONE IN NORMAL OPERATING CONDITIONS

Medical Conditions Generally Aggravated by Exposure
N/A

Emergency and First Aid Procedures
INHALATION: REMOVE TO FRESH AIR, SEEK MEDICAL ATTENTION
EYES: FLUSH WITH COPIOUS AMOUNTS OF WATER, SEEK MEDICAL ATTENTION
SKIN: FLUSH WITH COPIOUS AMOUNTS OF WATER, SEEK MEDICAL ATTENTION
INGESTION: SEEK MEDICAL ATTENTION. DO NOT INDUCE VOMITING.

Section VII - Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled
ANY SPILLED LIQUID SHOULD BE ABSORBED WITH AN INERT DRY MATERIAL AND PLACED IN AN APPROPRIATE WASTE DISPOSAL CONTAINER.
KEEP AWAY FROM HEAT AND SOURCES OF IGNITION.

Waste Disposal Method
DO NOT DISPOSE OF IN FIRE. FOLLOW ALL STATE AND LOCAL REGULATIONS FOR SOLID WASTE

Precautions to Be Taken in Handling and Storage
DO NOT PUNCTURE, DO NOT SHORT CIRCUIT, DO NOT OVERCHARGE, DO NOT OVERDISCHARGE
DO NOT MECHANICALLY ABUSE, DO NOT OVERHEAT

Other Precautions
DO NOT EXCEED 50°C **TRANSPORTATION: Li BATTERIES PER UN3090 PG II**

Section VIII - Control Measures

Respiratory Protection (Specific Type)
NONE REQUIRED UNDER NORMAL CONDITIONS

Ventilation	*Local Exhaust* N/A	*Special* N/A
	Mechanical (General) N/A	*Other* N/A
Protective Gloves	NONE REQUIRED UNDER NORMAL CONDITIONS	*Eye Protection* NONE REQUIRED UNDER NORMAL CONDITIONS

Other Protective Clothing or Equipment
NONE

Work Hygienic Practices
WASH THOROUGHLY AFTER USING THIS OR ANY BATTERY

U.S.G.P.O. 1986-491-529/45775

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ATTACHMENT 5—JOB FUNCTION CHART

ATTACHMENT 5—JOB FUNCTION CHART

Job function	Training	Requirement	Initial	Retraining	Reference
All employees	Environmental, Safety and Health Compliance Training*	Compliance Training Plan	Yes	Perm	Astronautics Compliance Plan
All new hires	New Employee Orientation Materials	ISO 14001	Yes	Perm	AP 04.18 Appendix E
All employees	Supervisor Checklist and Hazcom Briefing**	1910.1200	Yes	Perm	AP 04.18 Appendix E
Employees in jobs where hazardous waste is generated and managed including those engaged in emergency response and cleanup activities	Generator Awareness Annual Training (OJT)	40 CFR 265.16 6 CCR 1007-3 – 265.16	Yes	1 year	AP 04.18 Appendix E
Using and handling hazardous material other than normal use office supplies	Hazard Communication	HCP – Chemical Information System Handbook	Yes	2 years	AP 04.18 Appendix E
Employees engaged in hazardous material/waste response and cleanup activities	Emergency Response	OSHA 1910.120 6 CCR 1007-3 – 265.16	Yes	1 year	AP 04.18 Appendix E
Employees engaged in firefighting response	Fire Brigade***	OSHA 1910.156 6 CCR 1007-3 – 265.16	Yes	1 year	AP 04.18 Appendix E
Individuals affected by lockout and tagout. Need to understand program	Lockout/Tagout	Safety Standard OP-32.0	Yes	Perm unless program changes	AP 04.18 Appendix E
Individuals authorized to lock out and tag out equipment for servicing and maintenance	Lockout/Tagout for Authorized Employees	Safety Standard OP-32.0	Yes	1 year inspection	AP 04.18 Appendix E
When required to wear a respirator	Respirator Training****	Safety Standard PD-4.0	Yes	1 year	AP 04.18 Appendix E
When required to use Class I and II Lasers	Laser Class I and II	Safety Standard E-3.0	Yes	Perm	AP 04.18 Appendix E
When required to use Class III and IV Lasers	Laser Class III and IV	Safety Standard E-3.0	Yes	2 years	AP 04.18 Appendix E
When is designated Hearing Conservation area or function (above 85 db-TWA)	Hearing Conservation	Standard Procedure HR-10.09	Yes	1 year	AP 04.18 Appendix E
Operations identified by Radiation Protection Officer	Radiation Training****	Standard Procedure AM-02.13	Yes	Perm	AP 04.18 Appendix E
Entry into designated confined space	Confined Space	Safety Standard OP-2.0	Yes	Perm	AP 04.18 Appendix E
Any function requiring the use of protective equipment/gloves, goggle, faceshield, apron, etc.)	Personal Protective Equipment	Safety Standard PD-1.0	Yes	Perm	AP 04.18 Appendix E
Designated groups and functions with risk of exposure to pathogens associated with contact with untreated blood and body fluids. Defined in OP-42.0	Bloodborne Pathogens****	Safety Standard OP-42.0	Yes	1 year	AP 04.18 Appendix E
Functions using cab-operated cranes	Crane Operator	Safety Standard M-5.0	Yes	1 year	AP 04.18 Appendix E

Job function	Training	Requirement	Initial	Retraining	Reference
Employees operating Powered Industrial Trucks (PIT)	Powered Industrial Trucks	Safety Standard V-3.0	Yes	1 year	AP 04.18 Appendix E
Employees potentially exposed to open electrical of 50 volts or more	Electrical Safety	Safety Standard E-4.0	Yes	1 year	AP 04.18 Appendix E
Employees using elevated platforms such as scissor lifts, man lifts, etc.	Elevated Platforms	Safety Standard M-5.0 V-2.0	Yes	5 years	AP 04.18 Appendix E
Employees with potential for encountering asbestos-containing material on a regular basis	Asbestos Awareness	Standard Procedure HR-10.02	Yes	1 year	AP 04.18 Appendix E
Employees engaged in activities where protection is required to prevent falls from elevated areas	Fall Protection		Yes	3 years	AP 04.18 Appendix E

Note:	
Training courses are given through the Skills Training Department except:	Tracked in the ATTS Database
*Compliance Training CD Training system	Tracked on the Education Database
**Staffing	Tracked on the Education Database
***Plant Protection	Tracked in the ATTS Database
****ESH	Tracked in the ATTS Database

DP034_M2204

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ATTACHMENT 1—SAFETY PERFORMANCE AND INCIDENT/ACCIDENT HISTORY

NNG05EA01C
Attachment K

Mission Assurance Plan

Hubble Space Telescope (HST)
HST Robotic Vehicle (HRV)
De-orbit Module (DM)

July 10,2004

Goddard Space Flight Center
Greenbelt, Maryland

TABLE OF CONTENTS

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LIST OF FIGURES

Figure **Page**

APPENDIX B MISSION ASSURANCE PLAN (DID 1-1)

- All Lockheed Martin facilities are ISO 9100:2000 registered with AS9100 registration pending.
- GSFC's remote access to electronic discrepancy reports and Internet-based PMPCB provide visibility and participation throughout the program
- Hands-on participation by GSFC throughout fabrication and test via material and failure review boards

DP034_M2034

Introduction

This Mission Assurance Plan (MAP) builds upon the badgeless team environments successfully implemented on HST servicing missions and other programs such as MRO, XSS-11, Genesis and Spitzer. A web-based approach to Parts, Materials and Process Control Board (PMPCB) is implemented allowing seamless integration with GSFC and the LM Team. In similar fashion, GSFC's ability to remotely access Lockheed Martin's nonconformance reporting system enables effective monitoring of performance through custom reports.

Scope—This Mission Assurance Plan (MAP) applies to Lockheed Martin Space Systems Company (LMSSC) Business Units whose work affects HRVDM/HDV quality, to include those organizations encompassing LMSSC Programs, Product Centers, functional disciplines, and central support and remote-site organizations. This MAP fulfills the requirements of DID 1-1.

The requirements of this MAP are flowed to Lockheed Martin subcontractors via a separate Subcontractor Quality Requirements Document for Hardware and Software.

Field of Application—The Lockheed Martin Mission Assurance Program as detailed in this Program Plan is implemented at contract award and remains in effect throughout the life of the Program.

Organization/Manual Layout—This MAP documents the system that Lockheed Martin uses to design, develop, produce, test, and deliver the HST HRVDM/HDV to GSFC. A separate Quality Manual as required by DID 2-2 is summarized in Section 1.4 and will be provided after contract award as required by GSFC.

This plan generally follows the GSFC MAR in organizational style with the additions required by the GSFC surveillance plan (Exhibit 13).

Document Change Procedure—Once this document is baselined, any changes to it must be done formally. This requires that a Configuration Change Request (CCR) be processed through the Configuration Control Board (CCB) and submitted for GSFC approval in accordance with the DID.

Upon approval of this plan, subsequent changes are denoted by revision number (1, 2, etc.). Deviations from this plan require authorization by the Lockheed Martin Vice Presidents of Product Assurance & System Safety and Mission Success as well as the GSFC System Assurance
Manager.

Quality Engineers (QE) are assigned to be the primary interface with the PASSR. The QE and the PASSR jointly review the requirements to ensure that the product center/build area has the resources and ability to comply with the HRVDM/HDV quality requirements. The QE is responsible to ensure compliance to the quality requirements within the product center/build area and in support of the Integrated Product Teams (IPT).

The Quality Engineering Systems and Supplier Quality Assurance Organizations under the direction of the Vice President of Product Assurance & System Safety provide services and support for the PASSR as follows:

- Procurement Quality performs supplier evaluation, maintains the corporate supplier database, performs source surveillance, provides central receiving inspection support, and processes purchase documents imposing requirement flow-down per HRVDM/HDV Program QA direction.
- The Quality Laboratory performs chemical and physical testing of parts and materials, performs NDI inspections, and support failure analysis activities using their certified personnel as directed by engineering requirements and HRVDM/HDV Program QA.
- Central Product Assurance supports the HRVDM/HDV program as needed in the various labs and facilities at Lockheed Martin. Central Quality Engineering personnel perform scheduled assessments, maintain Command Media, support process improvement efforts, and assure compliance to AS9100 and corporate policies.

- The Lockheed Martin Technical Operations (LMTO) Metrology Laboratory performs calibration and statusing of measuring and test equipment items and maintains a recall system for items requiring periodic recalibration.
- The Test organization provides alternative facilities and personnel to support system level and environmental testing with oversight by HRVDM/HDV program QA.

Quality Engineers, integrated with the IPTs report directly to the PASSR providing direct oversight of design and build process. Use of common business system software-packages and procedures across product centers ensures Product Assurance and System Safety requirements are controlled and implemented consistently. Remote access to common defect reporting system by PASSR and GSFC allows effective oversight of fabrication and test process.

Subcontractors and suppliers are controlled within the IPT structure with Quality Assurance representatives providing the required oversight in accordance with program MAP requirements.

Checks and Balances—We have three layers of checks and balances to build in and ensure mission assurance throughout the system life cycle:

a. Engineering
   - Trained and certified CPEs with defined and monitored responsibilities
   - Peer reviews provide independent checks on design process

b. Product Assurance
   - MRB and FRB ensure proper disposition of nonconforming hardware and failure investigations
   - Parts, materials and processes control ensures proper selection, application and installation
   - Test procedure review

c. Independent oversight
   - LOB Chief Engineer provides independent path for CPEs
   - Mission Success Manager provides off-program technical advisement and oversight
   - Significant FRBs and all UVFs are reviewed by Mission Success and LOB Chief Engineer
   - UVF formal process via Senior Management Review Team. Our command media is instantiating a formal review process using a Senior Management Review Team (SMRT), with membership including VPs for Eng, PASS and MS. (Note: SMRT is only used for mission-critical UVFs, otherwise "next level down" review.) In addition, our SMRT is used for ad-hoc areas of critical concerns.

1 OVERALL REQUIREMENTS

Lockheed Martin's quality system facilitates GSFC participation in process

- All ISO elements fully implemented including required GSFC augmentations
- PASSR maintains direct oversight of HRVDM/HDV and is collocated with GSFC
- Electronic nonconformance reporting systems provides customer notification of failures and custom reports to facilitate independent assessment
- GSFC is full member of FRB

DP034_M2036

Introduction—This chapter addresses the overall HRVDM/HDV mission assurance requirements as well as responding to the GSFC Surveillance Plan in Section 1.3.

1.1 Description of Overall Requirements

This plan presents an organized mission assurance program that encompasses:

- All flight hardware, designed, built or procured by the LM Team or furnished by GSFC, from project initiation through launch and mission operations
- Ground support equipment (GSE) that interfaces to flight hardware to the extent necessary to assure the integrity and safety of flight items
- All software critical to achieving mission success.

1.2 Use of Multimission or Previously Designed, Fabricated or Flown Hardware

The LM Team maximizes use of heritage products in the design of HRVDM/HDV. Incorporation of heritage products in the HRVDM/HDV design requires a detailed review of the product's qualification history in comparison to the unique requirements of HRVDM/HDV.

Heritage products are subject to an Inheritance Review process that is led by the HRVDM/HDV Systems Engineering organization and the Certified Principal Engineer (CPE) with support from Product Assurance & System Safety, PMPCB, Software, Test, Mission Success and assigned customer representatives. The Inheritance Review process has been used successfully on the MRO program and addresses the following areas as a minimum:

- Comparisons of each performance, design, environmental, and interface requirement, including margins, for HRVDM/HDV with the corresponding previous requirement. For any mission requirement or environmental difference from the previous use, either the modifications to be made to the hardware and/or software to meet HRVDM/HDV requirements, or a rationale and supporting information demonstrating why use without modification is considered acceptable.
- Comparisons of each mission assurance requirement for HRVDM/HDV with the existing flow-down requirements. Areas that do not comply with the requirements of HRVDM/HDV are addressed by describing what shall be done to achieve compliance or by providing a rationale and supporting information demonstrating why the difference is acceptable.
- Parts and materials lists are reviewed as part of the Parts, Materials and Processes Control Board (PMPCB) process.

- A description of all ground and flight experience with the proposed hardware and software including, in particular, a description of all failures or anomalies, their cause, and any corrective action that was taken as a result are provided.
- The substantiating documentation is maintained by Product Assurance and will be available to the GSFC upon request. Once the design review process and all resulting action items are complete, any changes to the design or processes by the subcontractor require Lockheed Martin approval prior to implementation.

1.3 Surveillance of the Contractor

The work activities and operations of Lockheed Martin are subject to evaluation, review, survey, and inspection by personnel delegated by the GSFC Project Office. The activities of Lockheed Martin subcontractors and suppliers are also subject to evaluation, review, survey, and inspection, provided the activities are worked through Lockheed Martin contract management.

Lockheed Martin provides the government-designated Mission Assurance representative(s) with a copy of this plan and documents, records, equipment, and working areas within the facilities that are required by the Government designated representative to perform his overview.

Lockheed Martin works with the GSFC surveillance team to measure the health of the program by ensuring GSFC participation in program activities and facilitating collection and analysis of metrics of our performance. Lockheed Martin also facilitates traditional oversight methods including Government mandatory inspection of the work and approval of review board actions.

The remainder of Section 1.3 specifically addresses the requirements of GSFC's Surveillance Plan (Exhibit 13).

1.3.1 Program Surveillance

The Lockheed Martin Team supports the surveillance program by:

a. Ensuring GSFC formally participates in various working groups, reviews, surveys, audits, technical interchange meetings and inspections
b. Supporting informal discussions, telecons, reviews, and meetings between GSFC and the LM Team
c. Providing metrics
d. Coordinating with DCMA or GSFC delegates for implementation of Mandatory Inspection Points.

Lockheed Martin's badgeless approach to the HRVDM/HDV program ensures the GSFC will have visibility into the technical progress and issues and will have full insight into program schedules at all levels. Monthly Program Status and Quarterly Status Reviews, technical progress interchanges, and meetings of working groups further enhance this visibility.

The GSFC assigned Quality and Systems Engineers who periodically visit the LM Team facilities are invited to participate in various board meetings, conduct product inspections, monitor or witness tests, and assess processes.

1.3.2 Interfaces/Information Flow

The PASSR maintains close communications with the GSFC Mission Assurance team through weekly status reports and face-to-face meetings or telecons with the Systems Assurance Manager (SAM).

1.3.3 Product Verification (Inspection)

The Lockheed Martin build and test processes are available for the GFSC Mission Assurance team to monitor and witnesses as required. Lockheed Martin welcomes the identification of any required corrective actions as well as access to any needed GSFC resources to help resolve technical issues.

Lockheed Martin's nonconformance reporting system is described in Section 1.5.3 and is accessible to the GSFC SAM electronically to facilitate monitoring and participation in the process.

1.3.4 Mission Assurance Reviews

The Mission Assurance Reviews are addressed in Section 8 of this plan.

1.3.5 Review Boards

Lockheed Martin welcomes GSFC participation in a number of review boards. Details of the various boards and their methods of operation are provided in the referenced Sections below:

- Configuration Control Boards (CCB)—See Section 2 of this plan
- Parts Control Boards (PCB)—See Section 11 of this plan
- Corrective Action Board (CAB)—See Section 1.5.2 of this plan
- Material Review Boards (MRB)—See Section 1.5.3 of this plan
- Failure Review Boards (FRB)—See Section 1.5.3 of this plan

1.3.6 Audits

Lockheed Martin maintains a robust performance assessment process that includes:

- Assessments—Conducted in accordance with 3.5.2-T1-EntProc-1.1-P to ensure continual improvement of performance, products, processes, and services.
- Peer Reviews—Appropriate work products and processes (based on risk, criticality, and complexity) are selected and peer reviewed in accordance with 3.5.2-T1-MSuccess-1.2-P.
- Reviews—All project, program, functional, and business reviews required by Lockheed Martin processes or contract requirements are conducted in accordance with 3.5.2-T1-MSuccess-1.3-P, Reviews.
- Internal Audits—Internal Audits are performed by an independent organization in accordance with 3.5.2-T1-MSuccess-2.0-P to verify compliance and effectiveness of products, processes, and services.

GSFC representatives are invited to participate in joint audits as appropriate.

1.3.7 Safety

Lockheed Martin HST experienced systems safety personnel work closely with the HST Project Safety Manager and the systems safety and ES&H support to the IPTs, to ensure that all safety requirements are met and that any non-compliances are successfully resolved prior to launch. Additional details are provided in Section 3 of this plan.

1.3.8 Parts Control Board (PCB)

The GSFC Project Parts Engineer (PPE) is a member of the Lockheed Martin Parts, Materials and Processes Control Board as described in Section 11 of this plan.

1.3.9 Materials Controls

The GSFC Materials Assurance Engineer (MAE) is a member of the Lockheed Martin Parts, Materials and Processes Control Board as described in Section 12 of this plan.

1.3.10 Performance Verification

Lockheed Martin works closely with the GSFC Mission Assurance team to ensure they:

a. Review and comment on test plans, methods, and procedures prior to their application to any flight hardware
b. Participate in post-test reviews
c. Participate in Failure Review Board activities
d. Perform independent analyses of anomalies and failures.

1.3.11 Metrics

Together the PASSR and the GSFC Mission Assurance team develop suitable metrics after contract award to ensure visibility into the Mission Assurance Program. Typical program metrics include: the number of open/closed anomaly reports, anomaly reports remaining open more than 60 days, number of defects found by Government vs. Contractor inspections, and peer reviews planned/conducted.

1.3.12 Software Assurance

The Lockheed Martin Software Assurance program is highlighted in Section 5 of this plan and is detailed in the Software Management Plan that is delivered after contract award.

1.3.12.1 Formal Reviews

Lockheed Martin implements the formal reviews required by the GSFC Surveillance Plan and the Mission Assurance Requirements as noted in Section 5.3.1 of this plan.

1.3.12.2 Informal Reviews

Lockheed Martin personnel will support informal software reviews with its GSFC teammates. Design walkthroughs will be supported to ensure requirements traceability and to verify correctness and consistency of the design. Code walkthroughs are supported to verify the functionality of the code, to ensure coding standards are being followed, and that the software is traceable to the design and requirements. Test procedure walkthroughs are supported to ensure that the software tests verify the necessary requirements, that the tests are repeatable, and that sufficient data will be collected and analyzed. Action items initiated during these reviews will be tracked to closure.

1.3.12.3 Documentation Review

Lockheed Martin Software Quality Assurance reviews documents for compliance to data item description requirements.

1.3.12.4 Audits

The LM Team supports GSFC audits of our software quality management system. Action items initiated during these audits will be tracked to closure. The results of any NASA IV&V efforts are also provided to the surveillance team as required.

1.3.12.5 Change Activity

GSFC participates in the software configuration management system as described in Section 5 of this plan.

1.3.12.6 Metrics

Metrics of the Software Assurance program are maintained by the LM Team and are shared with the GSFC Mission Assurance Team. Metrics include:

a. Open defects
b. Closed defects
c. Defects remaining open for more than 60 days
d. Number of open high severity defects
e. Number of requirements vs. the number of original requirements
f. Percent of requirements yet to be satisfied through testing.

1.4 Quality Management System

Our quality management system–known as the LMSSC Product Delivery System directs processes and activities related to product design, development, procurement, production, test, and delivery. The British Standards Institute (BSI) registered Lockheed Martin on 26 March 1997. Since our original registration, the PDSM has been updated to meet the requirements of ISO Q9001:2000 with BSI registration on 29 April 2003. In May of this year, all of the LMSSC locations completed their assessment to AS9100 and registration is pending verification of corrective action for all minor nonconformances by BSI.

Additional details of Lockheed Martin's command media structure and implementation will be provided in the delivery of our Quality Manual as required by DID 2-1.

1.5 Supplemental Quality Management System Requirements

The supplemental Quality Assurance requirements defined in the MAR are addressed in subsequent Sections. A separate Quality Manual is to be provided after contract award in accordance with DID 2-1.

1.5.1 Configuration Management

Configuration management is described in Section 2 of this plan and will be addressed in greater detail in the Configuration Management Plan (DID PM-33) that is required after contract award.

1.5.2 Control of Nonconforming Product

Lockheed Martin maintains a closed loop system to ensure that products (hardware and software) that do not conform to drawings, specifications, or other engineering and technical acceptance criteria are properly identified, documented, segregated, evaluated, and dispositioned according to established and documented methods to prevent their unintended use. The system ensures that positive corrective action is taken to preclude recurrence as well as verification of the adequacy of the implemented corrective action via audit and test as appropriate. GSFC access to the system is described in Section 1.5.3.

Product Assurance & System Safety has primary responsibility to maintain the system to document, control, process, and disposition nonconforming product, whether on an individual basis or a common stock sweep, to assess the impact of suspect and/or nonconforming products and remove them to avoid further impacting quality.

Anyone can identify a nonconforming product, but Product Assurance & System Safety, manufacturing, or test personnel normally initiate the process. Preliminary Review and the MRB share the authority to disposition nonconforming product.

1.5.3 Material Review Board (MRB)

Before a nonconforming product reaches MRB, it goes through Preliminary Review. During Preliminary Review, authorized inspection, test, design, or manufacturing personnel determine if the product may be reworked to specification requirements, or if the product requires material review disposition.

The MRB is a formal board established to: (a) review, evaluate, and disposition nonconforming products, supplies, or material; and (b) ensure that corrective action is completed to preclude recurrence. Certified MRB members consist of: Product Assurance who chairs the board, the member who represents the design engineering organization, and the customer if required by the Program contract.

Test anomalies/failures are documented on a discrepancy document and require systematic documentation of troubleshooting and results to isolate the root cause of the failure and evaluate any possible overstress.

The FRB, in accordance with Lockheed Martin process, documents strictly controls the failure investigation process. Mandated structured troubleshooting (e.g., fault tree/fishbone analysis) and restrictions on breaking test configuration maximize opportunities for determining root causes. When the root cause cannot be found, a formal Unverified Failure review process is initiated with off-program management visibility.

A Failure Review Board (FRB) performs troubleshooting of anomalies, failure analysis direction, and determination of failure cause and implementation of corrective action for test failures. The FRB is chaired by Engineering (CPE at box level, Systems Engineering Team (SET) at subsystem and above) with additional representatives from Product Assurance, Test and the customer if required by contract. The FRB is limited in authority based on hardware level of assembly and type of failure. The CPE and Product Assurance must approve a break in test configuration recommendation by the FRB.

The Program Failure Review Board (PFRB) members include representatives from Product Assurance (chairman), the Program Office, Systems Engineering, Test and GSFC. The PFRB reviews and approves all test failures of flight hardware that are the result of a design deficiency, implement less than 100% retesting per the Project approved retest plan, or were unverified failures. The PFRB reviews and approves all FRB nonconformance closures at the HRVDM/HDV level of assembly. All failures, regardless of hardware type or level, are provided to PFRB members for review via custom reports from the electronic nonconformance reporting system. The PFRB has the authority to address any issues that may arise as a result of that review.

The specific areas of focus of the PFRB coupled with the visibility created by real time access to the electronic nonconformance reporting systems and its custom reports is a proven approach that was used successfully on the Terra Program. GSFC participation in the process is ensured through their membership in the PFRB.

1.5.4 Reporting of Nonconformances

Lockheed Martin has an electronic nonconformance reporting system (viz., Product Integrity Reporting System) that has been used successfully on other NASA programs. The system is remotely accessible to key customer representatives to provide visibility and involvement with the process. Custom reports are created to provide notification to GSFC of test anomalies beginning with the first power application at the start of end item acceptance testing or the first operation of a mechanical item and continues through formal government acceptance of the end item.

1.5.5 Control of Monitoring and Measuring Devices

Lockheed Martin provides for the control, calibration, and maintenance of all inspection, measuring, and test equipment that is used to fabricate, assemble, or demonstrate that products conform to requirements. The selection, control, and verification of measurement standards, measuring and test equipment, and processes follow approved procedures and industry standards. Calibration records are maintained. Subcontractors maintain similar calibration control.

The Lockheed Martin Technical Operations (LMTO) Metrology Laboratory has primary responsibility to control inspection, measuring, and test equipment and to maintain calibration records. Lockheed Martin's testing and calibration laboratories are compliant with the requirements of ISO 17025.

1.5.6 Flow-Down

The requirements of this Mission Assurance Plan are flowed to affected Lockheed Martin's subcontractors via a Subcontractor Quality Requirements Plan. Lockheed Martin has established a guidebook that provides best practices for subcontractor Mission Assurance. This guidebook is augmented with customer requirements and issued as a program specific document after contract award.

1.6 End Item Data Package

Lockheed Martin has implemented a process for Item Technical Data Packages (2.3.6-T1-DesEng-1.0-P-W4) that defines the minimum deliverable requirements for completed configuration items. This process enables flow-down of additional program deliverable requirements. For HRVDM/HDV, the requirements of DID 1-2 shall be implemented for in-house and all subcontractor and teammate flight deliverable items.

1.7 Applicable Documents

To the extent referenced in this plan, the applicable documents in Appendix 1 form a part of this document.

1.8 Acronyms, Abbreviations, and Definitions

Acronyms and Glossary are provided in Volume II of this proposal.

1.9 Proposed Alternatives

The LM Team proposes using a web-based approach to the PMPCB process as noted in Sections 11 and 12 of this plan. In addition, Lockheed Martin will leverage existing processes, particularly those developed through our IEP program to meet contract deliverables with GSFC approval whenever possible.

Lockheed Martin Systems Engineering may recommend that previously designed and flight proven products that used parts with other than Quality Level 1 be considered for acceptance at a lower screening level as part of the Inheritance Review process discussed in Section 1.2. For such cases, Systems Engineering provides a written recommendation to the PMCB indicating what effects, if any, on the mission reliability requirements result from the lower parts screening level. The PMPCB will review the Systems Engineering recommendation, the proposed parts list and the expected applications and environment and provide their recommended disposition of the parts. Any disputes between the Systems Engineering and PMPCB recommendations will be documented as a request for waiver and processed through the Project with recommendations attached to the waiver for supporting information as required.

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2 CONFIGURATION MANAGEMENT

Our CM approach features a co-design environment providing the closest and most productive relationship possible within CM

- Aligned with Level 3 Requirements of the HST Program Office Configuration Management Procedure (SCM1020D)
- Customer access to all released product data and work in progress
- Active customer participation in all processes
- Shared approval authority
- Efficient data transmittal
- Check and balance system to contribute to mission success, project performance and risk reduction

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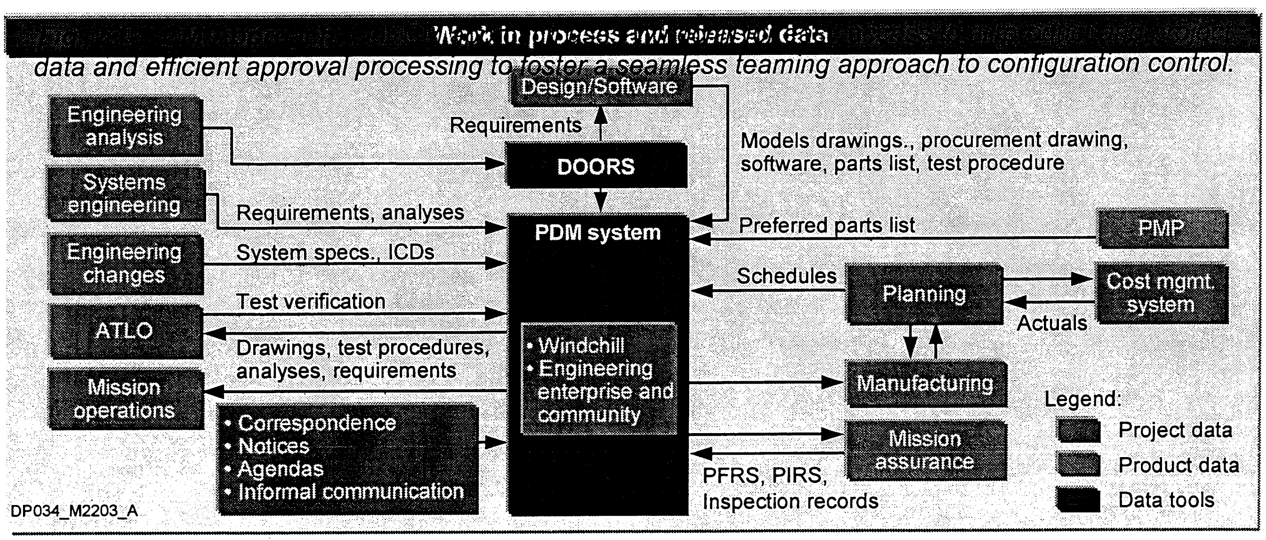
Our Configuration Management (CM) approach promotes a close and productive relationship and provides high visibility and efficient distribution of project data, documents and changes to all team members, creating a seamless integration within the system and allowing active Customer participation at all levels of CM tasks.

2.1 Configuration Approach

To achieve a close and productive team within CM, data must be seen by all team members, participation within meetings must be open, and control and approval authority must be clearly defined. The LM Team approach to configuration management provides many opportunities for GSFC/team member involvement at all levels of CM tasks, achieved primarily by using the Windchill product data management (PDM) system. By using Windchill, project data is able to flow freely between team members giving GSFC full visibility to all project data, documentation, and processes, as shown below in Fig. 2.1-1.

Configuration Management will assist in establishing and maintaining contractual baselines (including the flow-down to subcontractors), coordinating the change process for baseline changes, tracking the configuration, participating in reviews, audit and delivery, and providing data management. Our CM system has evolved over many years of collaboration with GSFC on projects including Hubble Space Telescope (HST), HST Servicing Missions 1, 2, 3A and 3B, Earth Observing System (EOS, also known as Terra), Landsat 7, and TIROS. Established processes are, and continue to be, updated from lessons learned. These processes are augmented with knowledge from more complex projects including Atlas, Titan, and Peacekeeper. We shall



collaborate with GSFC to ensure continual improvement of CM processes.

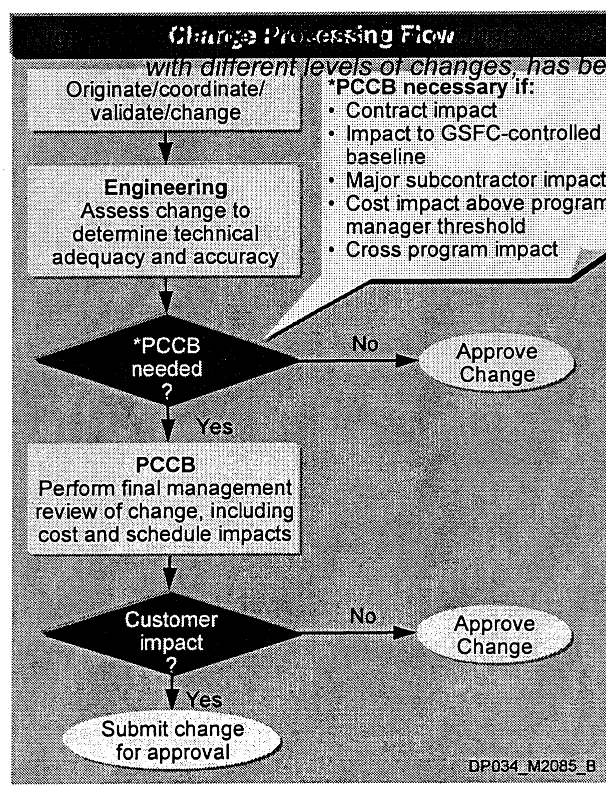
CM will provide a Configuration Management Plan (DILS PM-33) that describes the CM processes and includes requirement identification, engineering drawings, data and document release system, change control, status accounting, acceptance criteria, Data Management, and photographic documentation.

2.2 Configuration Management Board

The CM Chairperson will manage a disciplined change process to configuration-controlled baselines as the product matures. This includes the preparation of change requests, engineering and management evaluations of change requests, coordination with customer and internal business management and contract personnel, and following up on the implementation of approved changes. The Chairperson has the responsibility to convene a Program Configuration Control Board (PCCB) on a regular basis to approve or disapprove all configuration changes. The Chairperson will assure these changes receive adequate review from the PCCB members and to report on a monthly basis to HST Program Office Configuration Management. Figure 2.2-1 describes the change process flow.

CM collaborates with systems engineering, design engineering and Product Assurance to ensure that technical requirements, design, and product baselines are defined correctly. We shall provide a contract requirements document tree (CRDT), which not only describes and shows the relationship of contract and derived requirements documents, but also shows approval levels for changes to those documents as controlled by the established change system. By providing the CRDT,

project personnel and GSFC are able to see a clear baseline and know who controls which portion of it.



Changes to the baseline are made visible to GSFC through the Windchill PDM system. The LM CM team will collaborate with GSFC to determine the distribution for the change and set up the approval gates in the Windchill change lifecycle flow. CM ensures that technical and project requirements are accurately baselined and controlled in specifications, ICDs, subcontract SOWs, and design drawings. We provide the subcontract SOW and requirements document boilerplates and sign-off on these documents to ensure flow-down of contract, CDRL, and change requirements. We make sure changes are correctly incorporated.

Our system allows any team member to initiate a change, combines change meetings to increase efficiency, and establishes an efficient change process. It is important that GSFC and major subcontractors are very involved with the program change system. GSFC is required to be a part of the review process in addition to approving changes. Our change system emphasizes participation by GSFC throughout the process and evaluates initiated changes for cost and schedule impact along with technical completeness. To increase efficiency of the change process, changes are broken up into two classes: 1 and 2. Class 1 changes affect the contract requirements, including any baseline documents found within the contract. Class 2 changes affect contractor-controlled requirements such as test procedures, schematics, and engineering drawings. Major waivers are processed using the project change system and are maintained in Windchill, similar to engineering changes.

Any Class 1 changes directly affecting the contract are provided to the GSFC contract administrator for approval and subsequent contract negotiation and definition. The chief systems engineer chairs the Engineering Review Board (ERB) and provides technical approval of class 2 changes for the LM Team while working closely with CM in the change process. CM administers the ERB and co-chairs the PCCB.

An important element of this project is incorporating changes in a timely manner. Change planning is emphasized during every phase of the project. CM implements a change planning board to track and ensure accurate change incorporation. All changes are planned for implementation depending on the location of the item(s) and the incorporation point: prior to production, in-production, out-of-sequence, retrofits required, or modification kit required. GSFC will participate in the change planning board as required. Product Assurance is given change items to verify from the change planning process.

To facilitate a close co-design environment, the change management system provides opportunities for customer interaction throughout the change process. Representatives of GFSC are asked to participate in the PCCB and also co-chair the ERB with systems engineering. This interaction provides the GSFC team with both insight and oversight.

All changes are reviewed for cost and schedule impact. Engineering is expected to "precoordinate" changes and ascertain knowledge of the cost and schedule impact of the change before proceeding to ERB.

2.3 Status Accounting

Using Windchill, status accounting provides visibility of not only all project data (in-process and released) including project plans and technical memos, but also all product data, including design drawings, test procedures, subcontract statements of work and formal contract data requirement lists (CDRLs)/Deliverable Item List and Schedules (DILS). Change status provided in Windchill includes all changes initiated, in process, approved and rejected changes, and incorporation status by configuration end item effect. CM provides configuration status at test readiness review and major project reviews like Preliminary Design Review (PDR) and Critical Design Review (CDR).

Configuration status accounting reports are audited and provide prior to test readiness reviews. Configuration audits ensure that the hardware and software have incorporated all necessary changes, approved by the change process. If there is a need for further information or questions regarding the configuration status accounting system, a particular data item, or a CM process, CM personnel will work proactively with GSFC to provide the information or work solutions to the problem.

In addition to using Windchill to provide configuration status reports for test, project review, and acceptance activities, CM provides the configuration items list (CIL), consisting of part numbers

3 SYSTEM SAFETY

HST experienced systems safety engineers located in Greenbelt Maryland, will augment the systems safety engineers that are co-located with the IPTs.

3.1 System Safety Requirements

Established safety requirements form the basis of hazard analysis and assessment. Primary requirements documents are EWR 127-1, "Eastern and Western Range Safety Requirements" of version current at contract award, KHB 1710.2, "Kennedy Space Center Safety Practices Handbook" current revision, and NPG 8715.3, "NASA Safety Manual" current revision. Testing performed at GFSC must also comply with GMI 1700.2, "Goddard Space Flight Center Health and Safety Program," GSFC 5405-PG-8715.1.1, "Mechanical System Division Safety Manual – Volume I," and GSFC 5405-PG-8715.1.2, Mechanical Systems Division Safety Manual Volume II." System Safety coordinates these safety requirements to the project and verifies compliance.

3.2 System Safety Deliverables

3.2.1 System Safety Program Plan

The System Safety Program Plan required by DID 3-1, describes the process that meets the applicable launch safety and contractual requirements. The Plan details the safety tasks and activities to identify, evaluate, and eliminate and control hazards, or reduce risk to an acceptable level throughout the system life cycle consistent with NASA Safety Manual NPG 8715.3.

3.2.2 Safety Analyses

At a minimum, the following hazard analyses are prepared in support of HRVDM/HDV Safety Analysis Report (SAR)/ Missile System Prelaunch Safety Package (MSPSP)/ Safety Data Package (SDP) development:

- Preliminary Hazard Analysis (PHA)
- Subsystem Hazard Analysis (SSHA)
- System Hazard Analysis (SHA)
- Operations and Support Hazard Analysis (O&SHA)
- Software Hazard Analysis.

The SSHA, and SHA are developed from the foundation of the PHA. Other additional hazard analysis methods may be used, as needed, e.g., hazard analysis techniques described in LM AP 01.08, "System Safety Standard."

The Hazard Analyses shall:

- Identify hazards, hazard causes and determine needed corrective action
- Assess initial and residual risk
- Determine and evaluate appropriate safety design and procedural requirements
- Provide documented evidence of compliance with specified safety task, objectives, and design requirements for hardware, software and hardware/software interfaces
- Identify and evaluate design tradeoffs that affect system safety
- Support safety aspects of field and certification testing
- Be coordinated with designers to ensure technical correctness.

The results of each system safety analysis are used to influence the design activities through consultation with the design teams. Coordination with designers is beneficial to ensure accuracy and may lead to design solutions that reduce or eliminate hazard risk. Each analysis is carried to the depth permitted by the maturity of the design at each iteration. Hazard analysis results and documentation are made available to support Reliability, Maintainability, Human Factors Engineering, Test Planning, and Operations Planning. Hazard analysis results are reported in the SAR/ MSPSP/ SDP to support PDR and CDR. Final hazard analysis results are reported in the MSPSP 45 days before hardware ship to East Range.

3.2.2.1 Preliminary Hazard Analysis

The PHA is the initial documentation of credible system hazards. It forms the basis for all subsequent analysis. PHA is performed early in the design and development of the HRVDM/HDV system in order to identify inherent hazards and provide a basis for eliminating or controlling them. Hazard severity and frequency values are assigned for each hazard. The causes of the hazard and the effects the hazard on personnel, equipment, or operations are described and categorized for severity. For each identified hazard, control action is proposed to either eliminate or reduce the hazard occurrence to acceptable levels. The PHAs consider the following:

- Generic hazards list
- System and subsystem definition and interfaces
- Lessons learned from prior programs
- Environmental and operational constraints
- Materials and processes
- Operating, test, maintenance, and emergency activities
- Facilities and support equipment
- Safety related equipment and safeguards.

Potential hazards may be identified during system safety analyses, design reviews, safety reviews and informal design working group meetings. All hazards are identified and documented and remain as open system safety action items until formally resolved and closed.

3.2.2.2 Subsystem Hazard Analysis

The SSHA is performed to verify subsystem compliance to safety requirements of the hardware and software hazards within each subsystem. It identifies hazards associated with component failure modes, critical human error inputs, and hazards resulting from functional relationships between components and equipment comprising each subsystem. The SSHA is performed to the functional level.

3.2.2.3 System Hazard Analysis

Safety problems in the total system design are addressed in the SHA. The SHA identifies hazards and assesses the risk and compliance to safety requirements of the total system design, including software, subsystem interfaces and system functional faults. The SHA is performed at the subsystem interface level.

3.2.2.4 Operating and Support Hazard Analysis

The O&SHA identifies and evaluates hazards resulting from the implementation of operating and support activities performed by persons. It considers the following:

1. Planned system configuration and/or state at each phase of an activity
2. Planned environments (or ranges thereof)
3. Support tools or other equipment specified for use
4. Operations and/or task sequence, concurrent task effects, and limitations
5. Human factors
6. Regulatory or contractually specified personnel safety and health requirements
7. The potential for unplanned events including hazards introduced by human error.

3.2.2.5 Software Safety

Software that could be the cause of an identified hazard is subjected to software hazard analysis as noted in Section 5.2.1. Hazard analysis of software safety critical functions includes review of software requirements with respect to the hazard, verification of the software requirements in the end product, and a review of the software end product to ensure desired operation.

3.3 Safety Assessment Report

A safety assessment is performed by the LM Team to identify all safety features of the hardware, software, and system design. The assessment identifies hazards that are present in the system, specific controls, and precautions that the operating personnel should follow. The safety assessment report verifies that all identified hazards have been eliminated or controlled to the levels acceptable to NASA and that the HRVDM/HDV system is safe to test and or operate.

The SAR includes a statement signed by the HRVDM/HDV Program Manager to certify that all identified hazards have been eliminated, or their associated risks is controlled to an acceptable level and that the system is safe to test, operate, or deploy.

3.4 Missile System Prelaunch Safety Package

The Safety Assessment Report will contain the information required for the Missile System Prelaunch Safety Package. The requirements of EWR 127-1 are verified in a closed loop verification process.

3.5 Ground Operations Procedures

System Safety reviews operations procedures to ensure the proper safety precautions are incorporated. Results of the hazard analyses provide the baseline of these safety precautions. Procedures are also used to verify hazard controls as applicable. Procedures used at NASA facilities or other integration facilities such as at East Range are submitted to the host organization for approval as required.

3.6 Hazardous Operations

System Safety participates in test planning through the review and approval of procedures and attending pretest meetings. System Safety monitors hazardous operations through procedure approval. System Safety also places a priority on checking the test configuration and attending hazardous operations to ensure operational safety controls are properly implemented and to identify unacceptable residual risks. Operations shall comply with safety requirements of the host organization.

3.7 Safety Noncompliance/Waiver Requests

System Safety documents requests for waivers to requirements to which the project cannot practically comply. The request must include rationale for the requirement change and the alternate methods to adequately control hazard risk.

3.8 Support For Safety Meetings

System Safety supports project safety meetings such as the Payload Safety Working Groups described in NASA-STD-8719.8. Other meetings will be supported as needed such as Ground Operations Working Groups and SAR review.

3.9 Orbital Debris Assessment

Orbital Debris Assessment is covered in Section A-5 of this proposal.

3.10 Safety Requirements Compliance

System Safety performs a closed loop verification of safety requirements. A verification tracking log will be provided for all open verifications at the time of final SAR and Missile System Prelaunch Safety Package submittals.

3.11 Launch Site Safety Support

System Safety will be present at the launch site to maintain safety support of project operations through launch and coordinate safety activities with KSC Safety and Range Safety. Hazard analysis is nominally completed before launch site processing, but hazard control verification closure is expected to continue into launch site processing.

3.12 Mishap Reporting and Investigation

Mishaps and near misses are reported and investigated at Lockheed Martin in accordance with standard procedure PA 05.06, Mishap and Near Miss Reporting/ Investigating. A near miss is defined as an unintended event that had the potential to cause personnel injury, adverse impact to the environment, or significant system damage or loss to product (less than $10,000), hardware, ancillary equipment, or property in the performance of a program task, but did not (could be a result of a software anomaly). A mishap is defined as an unplanned event resulting in damage or loss of product hardware, ancillary equipment or property, or damage to the environment or unpermitted discharge into the environment in the performance of a program task. The mishap may involve personnel injury, but that is not the focus of this procedure. Reporting format is on a Flash Notice form per LM PA 05.06 as an equivalent to NASA Form NF 1627. Should a mishap occur at a GSFC facility, GPG 8621.1 and GPG 8621.2 will be used for reporting to GSFC.

The customer contracting officer shall be notified of any mishap resulting in fatality, lost-time occupational injury, lost-time occupational disease, contamination of customer property, or property loss of $25,000 or more arising out of customer contract work performed. Mishap investigation findings and corrective actions will be reported to the customer following the Lockheed Martin mishap investigation.

4 RELIABILITY ASSURANCE

Lockheed's successful Reliability Engineering program draws on best practices and Lessons Learned

- Comprehensive FMEA/FMECA, WCA, and other analyses performed early and often throughout the design process
- PRA quantifies reliability-related risks to trade off design alternatives and measure compliance with allocations
- Results of analysis are utilized by IPTs and systems engineering to optimize designs and reduce overall program risk
- Fault protection logic is prioritized and built-in from the start of conceptual design
- A Critical Items List continually tracks problem areas and mitigation plan status and promotes high visibility across the program

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Lockheed Martin's attention to reliability has delivered a superlative fleet of LEO and interplanetary spacecraft that consistently perform beyond their design lives. The key to our success is in application of proven principles and best practices of reliability, including (1) the adoption of high-TRL, heritage technology wherever possible; (2) careful attention to fault tolerance and FDIR; (3) use of high-quality, space-rated components; (4) exhaustive analysis and test regimens; (5) implementation of reliability-related Lessons Learned from past programs—MRO, Odyssey, CHAMP, Cassini, and many others—as internal command media, and (6) belief in reliability measures designed-in from the start, rather than implemented later as workarounds. LM's design philosophy has always held that the default configuration is the most reliable spacecraft feasible; positive decisions must be made to trade reliability for performance, cost, mass, or any other variable.

Our success is also attributable to the strength of our Reliability Assurance organization and its close integration with the efforts of Risk Management and Systems and Design Engineering. The Chief Systems Engineer (CSE) assumes the responsibility of satisfying all spacecraft design requirements, drawing on the resources of functional organizations such as Systems, Design, Safety, Reliability, EEE Parts, Materials and Product Assurance. The Reliability Engineer (RE) reports to the CSE and is responsible for planning, managing, implementing, and integrating the Reliability program into the total HRVDM/HDV program. The Reliability Assurance organization performs the bulk of the Technical Risk Management effort, though Risk Management may model cost and schedule impacts outside of the scope of Reliability. The RE coordinates reliability analyses with work done in other engineering disciplines to prevent duplication of effort; ensures flowdown of requirements and reliability design criteria to the appropriate design teams, reliability experts, and subcontractor/supplier management; monitors the reliability efforts of subs and suppliers and manages reviews of their analyses and models; presents the technical results of the reliability program tasks in monthly status reports and at program-level reviews and informal reviews; and recommends optimum numbers of spares of particular components. These roles take on increased importance in a program with HRVDM/HDV's accelerated schedules.

Reliability engineering calculations, analyses, and tests are performed by LM engineers, qualified subcontractor personnel, or reliability experts, all of whom work closely with systems and design engineers to ensure that models are of high fidelity. Lockheed Martin has retained ARES Corporation, world leader in risk and reliability analysis with extensive aerospace experience (including responsibility for PRA on the International Space Station), to assist in monitoring the reliability process and performing technical analyses, including PRA. Figure 4-1 presents the responsibility matrix for the HRVDM/HDV Reliability program tasks and identifies the lead for each task as well as any supporting functions.

	RE	SE	QA	Safety	CPE	Parts Eng	Material Eng	S/W
Reliability Design Criteria	S	P						
Trade Studies	S	P	S	S	S			S
FMEA	P	S		S	S			S
CIL	P	S	S	S		S	S	
PRA	P							
Allocations and Predictions	P							
Stress Analyses	P				S	S	S	
Worst Case Analyses	P	S			S	S		
Trend Analyses	P	S				S		
Lifetime Modeling	S		S		P			
Environmental Modeling	S	S			P			
S/W Reliability	S							P
Subcontractor Mgmt	S	P	S					
Parts Derating	S					P		
P = Primary Responsibility S = Secondary Responsibility								

4.1 General Requirements

Fig. 4-1 Responsibilities. *Reliability engineers work closely with design, systems, and other specialty engineering groups to implement our multifaceted Reliability Assurance program.*

RE tracks compliance with all reliability-related requirements in the DOORS database as documented in the Systems Engineering Management Plan (SEMP). These requirements include:

1. Fault protection requirements; e.g., hard-wired circuit fault protection to isolate electrical shorts per EEE-INST-002
2. Numerical allocations; e.g., 97% probability of mission success
3. Required analyses, such as FMEAs and PRAs
4. Lifetime requirements; e.g., a seven-year minimum from launch to deorbit
5. Environmental requirements, pertaining to radiation, MMOD, thermal, atomic oxygen, and other environments
6. Technology Readiness Levels
7. Margins and derating criteria
8. Other miscellaneous requirements.

Figure 4.1-1 lists examples of these types of requirements (for the HRVDM; HDV requirements are very similar) along with Lockheed Martin's historically successful approach to meeting them. Timely compliance with these requirements, demonstrated by test, analysis, or inspection, is the immediate responsibility of the Reliability Engineer and the ultimate responsibility of the Chief Systems Engineer. In the discussion that follows, we elaborate on those analyses and techniques Lockheed Martin employs to meet and exceed GSFC's expectations for technical risk management.

Type of Requirement	Example	Approach to Satisfying Requirement
Fault Tolerance/ Fault Protection/ Redundancy	3.3.4.8 No single point failures 3.3.4.5, 4.1.2.8 Circuit Protection & Fault Isolation 4.1.11.1 Single Fault Tolerance for mission objectives; 2FT for DM/EM sep 6.3.3.3.2.1 Functionally Redundant sensors 6.3.3.6.3 Two independent means of capture 5.10 Failure Detection & Correction 3.2.1.4 Range Rate Redundancy 6.3.1.11.2 HST fault isolation	• Identify and track SPFs and fault protection holes with FMEA/FMECA, FTA, and other analyses • Design in both functional and hardware redundancy for critical AR&C sensors • Baseline both berthing capture and soft dock • Isolate electrical shorts with multiple layers of switches and circuit breakers • Employ heritage SPIDER fault protection architecture
PRA	Required in SMR-5000	• Employ experienced PRA experts working with RM team and designers
Analyses	Required in SMR-5000	• Collaborate with design teams to identify all necessary parameters for WCA and other analyses • Perform aging or trend analyses on limited-life items • Draw on models from Math Models Database
Allocations	4.1.11 97% probability of successful deorbit 3.3.3.5 99% probability of no failure due to MMOD	• Establish compliance with requirements using PRA, FTA, math models
Lifetime	3.2.1.6 Pursuit, PR, R&C for a minimum of 1 year after launch 3.2.2.2 Deorbit anytime up to 7 years after launch 3.2.4.4 HRV Science Mission Life: minimum of 5 years from servicing completion 4.1.12 Shelf life + useful life must satisfy reqs 4.1.12.1 Shelf life = 3 years 4.1.12.2 Useful life = 7 years	• Aggressively track problem items on Limited Life List, with mitigation plans • Design CONOPS to preserve lifetime as much as possible • Provide environmental protection • Use conservative margins • Draw on experience from successes like Cassini, Odyssey
Technology Maturity	4.1.19 TRL of 6 required on all parts	• Reuse heritage HW and SW wherever possible from recent projects (MRO) • Recertify heritage technology in an inheritance review • Aggressively test and verify all non-TRL 6 items to qualify them by CDR
Environmental	3.3.3.5 99% probability of no failure due to MMOD 4.1.8.1 Impact of MM should be minimized 4.1.8.2 Radiation tolerance 4.1.8.3 Atomic Oxygen tolerance 6.3.1.15.1 Radiation tolerance consistent with orbital profile and lifetimes 6.3.1.15.1.1 Components selected to minimize radiation, including SEU 6.3.1.15.1.2 SEU tolerance 6.3.1.15.2 Atomic Oxygen tolerance	• Integrate radiation and MMOD shielding into the structural design and arrangement of components • Model environments according to best information available • Employ large margins against radiation TID, thermal cycles and worst-case temps, atomic oxygen, etc
Documentation	SE-03 Fault Protection Requirements Document SE-04 Fault Protection Description Document	• Work closely with design engineers to fully understand and document intricacies of the design • Provide complete documentation and traceability for all analyses
Parts	4.1.2.5 EEE parts meet GSFC-PPL-21 standards	• Meet and exceed all derating and other criteria, verified by comprehensive parts stress analysis
Does not include supplementary requirements (e.g., those specifying MMOD flux models or radiation models), repeated requirements, software requirements, and some requirements for which RE is not primarily responsible.		

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Fig. 4.1-1 Key Requirements. *Lockheed Martin's long experience similar vehicles, application of heritage technology, robust fault protection architecture, and commitment to comprehensive analyses and high-visibility Risk/Reliability information guarantee satisfaction of all of GSFC's requirements.*

4.2 Probabilistic Risk Assessment (PRA)

PRA is a predictive tool that combines fault trees and event sequences to model complicated accident and failure scenarios in systems with multiple layers of redundancy. To perform an event-tree based PRA, reliability engineers, working closely with mission and spacecraft designers, define sets of initiating events (failures that will lead to system-level failures if not properly mitigated), pivotal events (additional exacerbating failures or conditions), and end states (undesirable contingencies like "Collision with HST", "failure to deorbit," etc). The initiating events (IEs) describe the basic failure that triggers the accident sequence, at a level consistent with the Failure Modes and Effects Analysis (FMEA) database. Generally, an IE is a failure mode at the subassembly or assembly level, usually identified with the help of a Master Logic Diagram (MLD). Each IE-induced scenario is then developed in an Event Tree (ET), possibly through an intermediary Event Sequence Diagram (ESD) (Fig 4.2-1). Each logical pathway branches at any number of pivotal events (PE), and terminates in a single well-defined end state (ES) describing a particular degraded mode or outcome (see Fig. 4.2-2).

The IE and each of the PEs are associated with probability distributions defining their likelihood of occurrence, with associated epistemic uncertainty, under the conditions holding for a particular ET. The probability distribution may be a simple user-defined function (normal, lognormal, Weibull, etc.) or may be calculated instead as the top-level event in a Fault Tree (FT) built of logical combinations of lower-tier basic events. Using this combination of event and fault trees, probability distributions are propagated through the models to determine the probability of all the end states. If the likelihoods of certain end states are unacceptable, modifications to the event and fault trees can be used to model means of mitigating the probabilities or consequences.

We derive failure rates of the basic events that populate a fault tree at the lowest level from a variety of sources, including LM and supplier/contractor databases; generic volumes like MIL-HDBK-217, NPRD, EPRD, Bellcore/Telecordia, etc.; and on-orbit anomaly data from similar programs. Where necessary, we apply appropriate environmental and dormancy conversion factors to transform data observed in one environment into data relevant for HRVDM/HDV. Generally, we use a stress analysis approach to reliability prediction based on MIL-HDBK-217, assuming a constant component failure rate (exponential survivor function). Based on historical data or results of special engineering tests, accelerated life tests, or parameter trends analyses, however, we develop prediction models that use variable failure rates, such as the Weibull failure probability distribution and/or the Birnbaum-Saunders fatigue life distribution.

New failure data—from discrepancy reports, newly published sources, or failures of similar

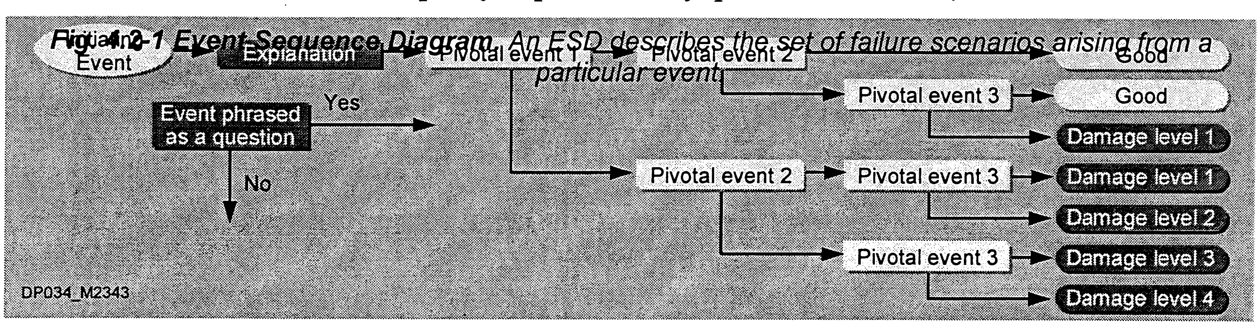


Figure 4.2-1 Event Sequence Diagram. An ESD describes the set of failure scenarios arising from a particular event.

components in other programs—is incorporated via Bayesian updating. Bayesian updating is a rigorous mathematical framework for combining an analytically derived "prior" probability

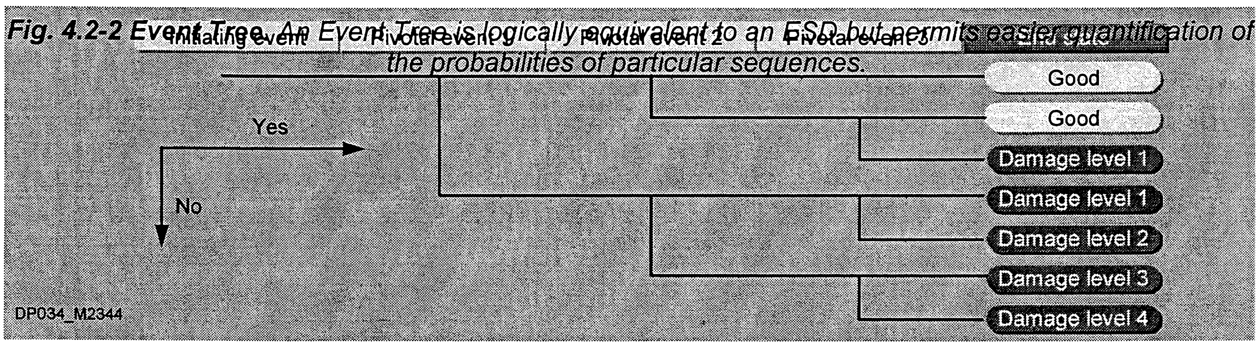


Fig. 4.2-2 Event Tree. An Event Tree is logically equivalent to an ESD but permits easier quantification of the probabilities of particular sequences.

distribution with new historical "evidence." In HRVDM/HDV's case, the prior is the existing distribution arising from sources such as MIL-HDBK-217, etc., (which may itself have been arrived at via Bayesian update). The combination of equally credible prior and evidence is a single probability distribution, referred to as the "posterior," that more closely identifies the range of expected values than any approach which makes use of only one of the sources. Since there is no extant evidence for vehicles identical to HRVDM/HDV (unlike, for example, data used to update Shuttle models), we modify the evidence constructed from other, similar flight experiences to allow for a measure of its applicability to the HRVDM/HDV. We accomplish this via the use of weighting factors on historical evidence: higher weights, indicating more relevance to HRVDM/HDV, leave the evidence essentially unchanged; lower weights transform the evidence, mathematically, into less statistically relevant data, resulting in a more uncertain posterior
distribution.

A comprehensive, system-level PRA is a powerful technical risk management tool that will prove useful for much more than verifying compliance with our allocations. By quantifying the probabilities of failure of design or operations alternatives in a rigorous way, we place reliability on the same numerical footing as cost or performance (usually easier to quantify) in trade studies, removing subjectivity from the trade. We also expect PRA to be useful for revealing problematic areas of the design overlooked in other analyses helping to prioritize technical risks.

The Risk Management organization shares responsibility for technical risk management with Reliability Assurance, and both are owners of the PRA. By modeling proposed risk mitigation strategies in the PRA, we can quantify their risk reduction value and select the most effective alternative. In recognition of PRA's value to the program as a quantitative risk-tracking tool, Reliability Engineering will allocate a large percentage of its resources to preparation and maintenance of a mission phase-specific PRA, compliant with the *PRA Procedures Guide for NASA Managers and Practitioners*, and will document our approach in the PRA Planning Document (PM-47). We continue to refine the PRA up until CDR, and will update it thereafter to reflect any design changes, new information on component failure rates or aging tendencies, and risk mitigation strategies.

4.3 Reviews and Reports

Reliability status is tracked in monthly status reports and in all major program reviews, where program management reviews the current status of test and analyses, verifies that the space system is on track to meet all reliability requirements, reviews discrepancy reports, reviews parts testing and evaluation status, processes waivers, signs off on V&V tests, and assigns responsibilities for new tests and analyses as needed. Design reviews ensure that the overall

Reliability program is proceeding in accordance with the contractual milestones and that all systems are appropriately balanced on dimensions of safety, reliability, performance, cost, and schedule. Reliability technical exchange meetings are held on an as-needed basis.

4.4 Reliability Allocations

Concrete, quantitative reliability goals encourage thoughtful design and early mitigation of failure modes. Two quantitative allocations are specified in the GSFC Requirements Document:

1. 99% probability of no failure due to the MMOD flux specified in NASA TM 100-471.
2. 97% probability of successful deorbit, following orbit insertion.

Compliance with the first of these will be assessed via mathematical modeling of MMOD flux, vehicle geometry and trajectory, and the spatial arrangement of components inside the primary structure. The second, more general allocation will require fault tree analysis or PRA. The reliability engineer (RE) is responsible for apportioning allocations to the subsystem level, consistent with the top-level number, and assigning acceptable probabilities of failure to cognizant design engineers. If a subsystem (or assembly) is found to be out of compliance, the IPTs must reallocate failure probabilities within their scope. If necessary, the RE or his delegate may reallocate failure probabilities among subsystems, consistent with the top-level requirement; if reallocation is impossible, then a redesign will be required. This process is iterative and is repeated as the design grows in detail.

4.5 Reliability Analyses

Reliability analyses may be either qualitative or quantitative. Quantitative analyses like worst case analysis (WCA) or fault tree analysis (FTA) produce predictions used to measure compliance with allocations and specifications, compare alternative architectures, and prioritize technical risks. A suite of qualitative analyses such as FMEA/FMECA or sneak circuit analysis (SCA) complements the quantitative analyses by 1) encouraging the design of robust, fault-tolerant systems with inherently high reliability, before reliability is ever explicitly measured, and 2) exposing hidden failure modes or sneak paths that might otherwise elude number crunching. Analyses are performed to evaluate HRVDM/HDV performance over the expected mission profile, possible worst-case deviations, and during ATLO, including risks associated with packaging, handling, storage, and transportation (PHST). The required analyses are performed concurrent with the design program to ensure identified problem areas can be addressed by the IPTs and corrective action taken, if required, in a timely manner. All analyses used to measure compliance with HRVDM/HDV requirements will require peer reviews, and documentation of all analyses will be made available to GSFC upon request.

By PDR, Reliability Assurance will document the objectives of the Reliability program, the ground rules and requirements for all reliability analyses (including FMEA/FMECA) and fault tolerance requirement assessments in the Fault Protection Requirements Document (FPRD) as required by DRD SE-03. The FPRD will include the Critical Items List (CIL), along with documentation of the program-specific criteria that will be used to screen items for inclusion on the CIL. By CDR, the results of these analyses, as well as a complete description of the fault protection designs implemented in hardware and software, are included with the Fault Protection Description Document (FPDD) as required by DRD SE-04.

4.5.1 FMEA/FMECA and Critical Items List (CIL)

Lockheed Martin's unique experience servicing Hubble on CHAMP and SEAT will prove invaluable as we submit the HST-HRVDM interface, EM-DM interface (in HRVDM), and all functional blocks in our design to a Failure Modes and Effects Analysis (FMEA). We employ MIL-HDBK-1629-compliant FMEA to capture key information on each failure mode at the lowest practicable level and the impact of the failure on mission operations assessed at higher levels of assembly. The analysis of the impact includes details on failure detection and steps required for failure mitigation. Since Lockheed Martin concurs with MIL-HDBK-1629 (now cancelled), *Procedures for Performing a Failure Mode Effects and Criticality Analysis*, that "timeliness is perhaps the most important factor in distinguishing between an effective and an ineffective FMEA," we perform FMEAs as soon as adequate design information is available. Reliability engineers collaborate with design engineers intimately familiar with the HRVDM/HDV system in the performance of FMEA, and work closely with designers to translate failure mode information into immediate design improvements.

For PDR, the RE will perform an FMEA on all spacecraft flight hardware designs at a level low enough to identify all single-point failure items. Analysis of redundant equipment will address cross-strapping to ensure that no single failure adversely affects the performance of the redundant capability or propagates to other parts of the system. The list of single-point failures represents candidates for elimination through the detailed design process; any exceptions (such as structural failures) require a GSFC-approved waiver. To date, we have identified no single failure points in our design besides normally waived structural failures (tanks, primary structure, propellant manifold, etc.) and a failed-closed regulator in the propulsion system (of historically very high reliability). We will continue to flag and circumvent possible single point failures or common cause susceptibilities as the design progresses to finer levels of detail and the FMEAs are iterated at lower levels toward root causes—the old failure modes becoming the new effects. The RE provides the common definitions, criticality classifications, nomenclature, numbering schemes, forms and depth of analysis required for the FMEA's incorporation into the FPRD.

For CDR and thereafter, we extend the FMEA to a criticality analysis (FMECA) by assigning a severity category and a likelihood to all failure modes at the subsystem and system levels. The criticality rankings will be used to prioritize technical risks according to their impact on the program. More details on program-specific FMEA/FMECA, including details of the likelihood and severity scores used for criticality ranking, will be included in the FPRD.

FMEA is a primary means of flagging candidates for inclusion in the Critical Items List (CIL). The CIL, included with the Fault Protection Requirements Document (SE-03), highlights those hardware items that represent significant risk to a program, presents the rationale for their retention, and/or defines the controls that are implemented on each. Generally, most CIL elements either 1) are single points of failure, 2) are (potential) limited-life items, or 3) do not meet their mandated derating criteria. Complexity, lack of historical data, and history of poor performance may also qualify items for the list; the precise criteria for inclusion will be specified in the FPRD. Each element of the CIL is accompanied by rationale for retention in the design, risk mitigation plans and corrective actions, recommended tests and analyses, and other data. At CDR and subsequent reviews, uncorrected problems are highlighted to determine the necessary design action. Reliability Engineering tracks the critical items closely and verifies that requirements are met and properly documented.

Because HRVDM/HDV enjoys a high TRL and a high degree of heritage, we do not expect a lengthy CIL. Currently, we are considering for inclusion a few limited-life items like solar arrays and batteries; structural single points of failure; and low-TRL items like the soft-dock latches.

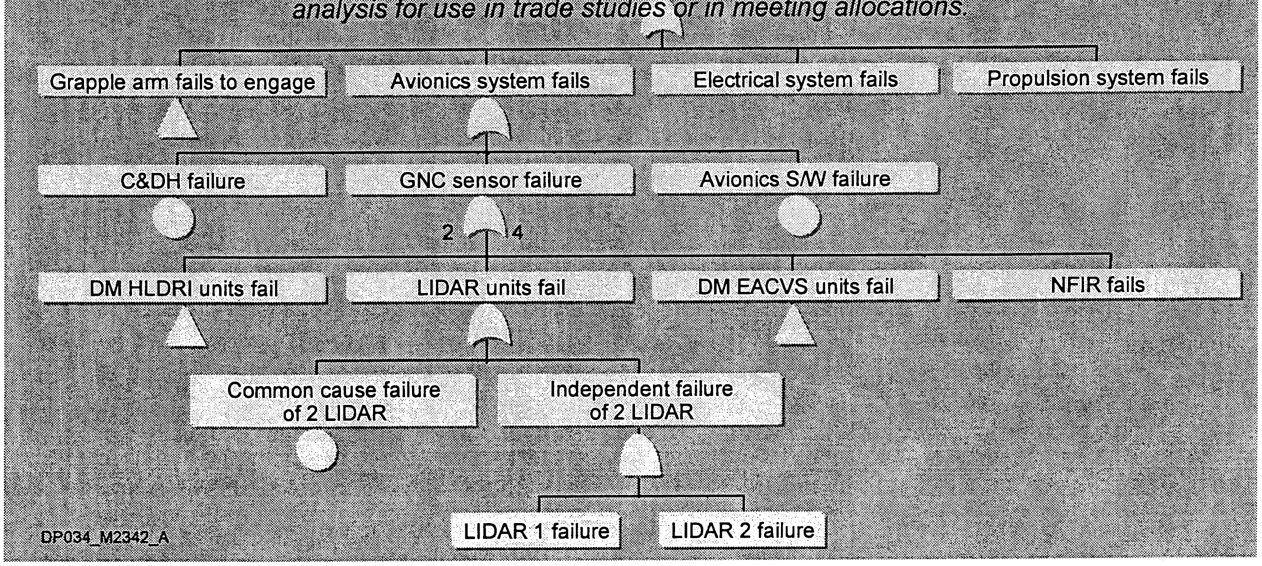
4.5.2 Fault Tree Analysis (FTA)

Fault tree analysis addresses both mission failures and degraded modes of operation by enumerating exhaustively all combinations of component failures leading to a particular undesired end state. FTA may be either qualitative or quantitative and may be used to gain insight into a particular architecture, to quantify failure probability in order to measure compliance against an allocation, or to trade off alternative designs. FTA usually considers the same effects and many of the same causes as FMEA, but extends this analysis by considering the effects of multiple simultaneous component failures. Component failures, external events, software failures, and human factors will be eventually considered in the analysis, which grows in fidelity over the course of the design phase. FTA products are an essential component of Probabilistic Risk Assessment, discussed above. Figure 4.5-1 shows a simple fault tree implemented in the SAPHIRE code.

4.5.3 Parts Stress Analysis (PSA)

Flight hardware Electrical, Electronic and Electromechanical (EEE) parts and devices are subjected to stress analysis for conformance to the EEE-INST-002 derating policies described in the Parts Requirements Section of this plan (11). Part stress analysis, sometimes considered a component of worst-case analysis (see below), examines individual parts to ensure that the stress due to combined effect of loads, degradation, piece part variation, fatigue, and other exacerbating conditions does not exceed the applicable EEE-INST-002 derated value. Reliability engineering, parts engineering, and design engineering all perform PSA in accordance with existing Lockheed Martin procedures, EG 2.3.5.5.4, *Electrical Worst-Case and Parts Stress Analysis Guidebook.* We submit all applications not meeting the derating requirements to the PMPCB for approval as noted in Section 11.6. All approved part applications not meeting the derating criteria are included on the CIL.

Fig. 4.5-1 SAPHIRE Fault Tree. *Fault trees incorporating system logic permit quantitative reliability analysis for use in trade studies or in meeting allocations.*



4.5.4 Worst Case Analysis (WCA)

Worst-case analysis of all critical circuitry also follows the guidelines in EG 2.3.5.5.4, *Electrical Worst-Case and Parts Stress Analysis Guidebook.* WCA is performed at higher levels of assembly than PSA and qualifies circuits or functional blocks against worst-case combinations of temperature, aging and degradation effects, radiation effects, shock and vibroacoustic effects, loads, and voltage/current inputs and transients. WCA on mechanical and electromechanical parts verify functionality and compliance with safety factors and design margins at worst-case combinations of manufacturing tolerance, thermal environment (taking into account CTE and brittleness), radiation embrittlement, aging effects, acceleration, shock, vibroacoustic loading, and mechanical loading. The WCA is performed using the parameters identified in EG 2.3.5.5.4 and considers all operating modes of the component; detailed calculations need only be made at the conditions that produce the most severe results.

WCA of electronic circuits may be performed either analytically or by use of computer aided design (CAD) software. For analysis that involves three or less independent variables, we generally use extreme value analysis for the worst case parameters; analysis involving more than these independent variables may substitute averaging techniques such as root-sum square (RSS). Interfaces are considered to be external stimuli or loads that effect the operation of the component. Where appropriate, we consider sensitivity to EMI (noise) effects, timing variations, harness and backplane effects, phase and gain margins, among other parameters.

4.5.5 Reliability Assessments and Predictions

MIL-STD-756, *Reliability Modeling and Prediction* (now cancelled), illustrates the use of PRA, Fault Tree Analysis, and other mathematical models for the measurement of compliance with quantitative requirements. Such models may also be employed toward the evaluation of alternative designs or architectures or the tagging of problematic areas in the design for further work, as described elsewhere in this section.

4.5.6 Other Analyses

In conjunction with design engineers and personnel from other specialty disciplines, Reliability Engineering performs additional analyses as required to verify compliance with reliability requirements, support design engineers with detailed modeling, trade design options for reliability, or improve robustness or fault tolerance. These additional analyses include:

- **Single Events Effects Analysis**—SEEA considers upsets (including multiple bit upsets like those observed on Cassini), transients, latchup, burnout, and gate rupture;
- **Sneak Circuit Analysis**—SCA is used to guarantee that no malignant sneak paths from power distribution to safety-critical and cold-spare circuitry exist;
- **Thermal Stress Analysis**—Thermal analyses predict the system's compliance with allowable flight temperatures (AFT) under worst-case conditions, and to consider the effect of thermal cycling on materials known to experience thermal wear-out (solder joints, conformal coatings). Reliability Engineering does not own thermal math models but may contribute to them or utilize them for other analyses.
- **Structural Stress Analysis**—SSA verifies compliance with mandated safety factors.
- **Dormancy and Aging Analysis**—The HRVDM/HDV must perform correctly (with a probability of 97%) after many years of dormancy. Dormancy and aging analyses are used to

derive failure rates that are functions of time, improving the fidelity of PRA and other analyses.

- **Common Cause Failure Analysis**—In highly redundant systems like those on HRVDM/HDV, common cause failure becomes a major reliability driver. RE will investigate all plausible common cause failure modes.
- **Functional Failure Analysis**—FFA is an extension of FMEA that considers the times-to-effect of distinct failure modes. FFA is useful for designing autonomy into fault-protection architecture.
- **Lifetime Analyses**—These include modeling of consumables or degradation as in Solar Array Life Test Analysis and Battery Cell Life Analysis. Reliability will review these analyses as performed by design teams, and will contribute to or perform lifetime analyses as necessary.

A summary of reliability analyses and other features of Lockheed Martin's reliability program, along with their benefits to the program, is found in Fig. 4.5-2.

4.5.7 Analytical and Modeling Tools

Consistent with other NASA programs, including the Space Shuttle and the International Space Station (ISS), we construct PRA and Fault Tree models using INEEL's SAPHIRE computer code. (If NASA decides to transition the Shuttle and ISS models to another risk assessment platform, such as QRAS, we will make a similar transition.) SAPHIRE is an integrated cutset-based PRA package with fault tree and event tree capability and support for Monte Carlo/Latin Hypercube sampling on Weibull, lognormal, normal, and other distributions. We also utilize industry-standard Relex-brand reliability software products in many of our analyses, including FMEAs, and perform some additional calculations in Microsoft Excel with Monte Carlo simulation plug-ins like Decisioneering's Crystal Ball or Palisades' @Risk.

4.6 Analysis of Test Data

Test data is analyzed in accordance with Lockheed Martin's Test Engineering Process (2.3.8.1-T2-Test-1.0-P). Post-test data assessment consists of a review of test execution to ensure that:

- All test objectives have been met
- The data collection process has provided valid data
- It is safe and appropriate to disassemble the current test and continue to the next integration or

Fig. 4.5-2 Reliability Analyses. *A broad suite of comprehensive analyses provides a check on the work of design and systems engineers and identifies areas for improvement.*

Analysis	Benefit
FMEA/FMECA	• Comprehensive method for discovering single failure points • Design teams bring complete knowledge of the system to the FMEA • Results can be immediately incorporated in design iteration to correct fault tolerance deficiencies
PRA	• Systematically derives quantitative estimates of reliability for complicated systems and scenarios • Useful for trade studies, to identify problem areas, and to verify allocations • Establishes interface between Reliability Engineering and Risk Management
WCA	• Guarantees that components will not be loaded beyond capacity even in worst-case parameter combinations
Stress Analyses	• Establishes compliance with parts derating criteria • Identifies non-compliant parts for inclusion on the CIL
Trends Analyses	• May identify problematic limited-life items • Supplements accelerated life testing and historical performance data as input to aging models or PRA
Other Analyses	• May includes SEEA, SCA, aging and dormancy analyses, common cause analyses • RE reviews and assists design teams with thermal and structural analyses • Supplement and extend FMEA and PRA to illuminate non-obvious or complex failure modes

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test activity.

Results of the test procedure are analyzed to determine if the established success criteria have been met, lessons learned identified, and as-run procedures and resources evaluated. If a product fails to meet any specified success criteria, results are documented on a nonconformance report and the cause of the failure investigated as discussed in Section 1.5.3.

The CPE then performs a Product Certification process (e.g., 2.3.6-T1-DesEng-1.0-P-W6-C1) that includes a detailed review of test data, trend data, verification requirements, results of failure investigations and other items detailed in the process checklist. The certification is a formal document that is completed by the CPE, Product Assurance, systems engineering and others as required by the program certification plan. The completed certifications will be available for review through the Windchill system described in Section 2.

4.6.1 Trend Analysis

Measurable parameters that relate to performance stability shall be determined by Systems Engineering and tracked in the System Performance Verification Plan, which ensures flow down of the requirements to the lower level plans and procedures. In some cases, the data are observable from the start of component level test through mission operations; in others, the data are not meaningful or observable until interfaces between components or subsystems are established. Test engineers record the values of trending parameters at frequent intervals during the testing process and plotted against calendar time or duty cycles to illuminate wear-out effects. Trend analysis reduces uncertainty about the survival of life-limited components, and in so doing may red-flag problematic components or reduce risk for those components that behave better than expected. The LM Team reviews trend analysis with operational personnel prior to launch.

4.6.2 Analysis of Test Results

Testing occasionally uncovers new failure modes, sneak circuits, or fault protection deficiencies that have eluded FMEAs and other analyses. Testing may also indicate higher or lower failure rates for particular components, longer or shorter lifetimes, or different operational environments than previously believed. Reliability Engineering continually evaluates the results of all test reports and update failure data and analyses as necessary. Problematic components discovered in testing will be considered for inclusion on the Critical Items List. Failure investigations are also evaluated for any reliability implications as part of the FRB process.

4.7 Fault Protection

GSFC mandates single-fault tolerance for all mission-critical functions, dual-fault tolerance for DM-EM separation (in HRVDM), functional redundancy in both AR&C-critical sensors and capture methods, and dual-redundant C&DH processors with safe hold back-up, among other requirements. Lockheed Martin meets these specifications by judicious use of overlapping capability/functional redundancy, N+1 block redundancy, cross-strapping, and operational flexibility (e.g., two entirely different modes of capture). We accept the additional complexity introduced by cross-strapping (in the HRDD telecom system, for example) wherever the criticality of the components involved outweighs the failure probability and consequence of the switching apparatus. Lockheed Martin's general approach to fault tolerant design will be spelled out in more detail in the FPRD and FPDD.

Lockheed Martin's long experience with highly autonomous spacecraft like Odyssey and XSS-11 indicates that distributed fault protection logic leads to faster response times, easier segment integration, and more complete fault coverage. HRVDM/HDV will fly with the heritage SPIDER fault-protection architecture successful on Stardust, Odyssey, Genesis, and other programs, which accomplishes robust defense-in-depth by isolating faults at the lowest possible level. Failures are caught first by component-level fault protection (CLFP) in the hardware controllers—for example, after hard-coded switches in a Distribution Support Electronics Package (DSEP) open to isolate a shorted circuit board. CFLP passes information about the failure to performance-level fault protection (PLFP)—which might bring online a redundant board in our example—and finally to system-level fault protection (SLFP), where systemic responses like safe mode may be actuated. By supplementing FMEA with a functional failure analysis (FFA), reliability engineers will, as requested, assist software and systems engineers in allocating fault recovery mechanisms to ground and spacecraft, depending on the criticality and time-to-effect of a particular failure mode. SPIDER handles failure events autonomously when response time is critical, and includes ground in the loop when appropriate. (See the section on Flight Software, A-2.1.11, for more discussion of the SPIDER architecture.)

SPIDER (and any fault detection and recovery architecture) is more effective when conservative margins yield the flexibility to work around anomalies on-orbit. On past programs, Lockheed Martin has consistently met and exceeded required power, energy, processor throughput, and other margins; MRO, with which HRVDM/HDV has much in common, improves on the required power margin by 9% and processor throughput by 20%. HRVDM/HDV's current baseline margins are listed in Section A-3.7, *Operational Margins and Effectiveness*.

4.8 Technology Maturity

Use of heritage hardware is both a cost-saving measure and an enhancement to reliability. On a short-duration, time-critical project like HRVDM/HDV, inheritance is essential; Lockheed Martin therefore utilizes almost exclusively high-TRL components on this program. We will perform inheritance reviews on all S/W and H/W adopted from other programs to verify that the values of all critical parameters expected on HRVDM/HDV are appropriately enveloped by the original qualifications. For HRVDM/HDV, extensive adoption of our experience in XSS-11, MRO, Odyssey, and other programs has produced a system of 98% heritage hardware. C&DH, along with 80% of FSW, is inherited directly from MRO; the propulsion system is adapted from MRO. Much of the LIDAR and other ARPO technology critical for rendezvous and docking with HST has been demonstrated on XSS-11 and incorporated into DART and Orbital Express. We aggressively test and verify all items without a lengthy heritage (e.g., the newly designed soft dock mechanism) to bring them to TRL 6 by CDR.

4.9 Limited-Life Items

Lockheed Martin has an excellent track record in the design and manufacture of space vehicles for long-duration missions, both earth-orbital and deep-space. The flawless performance of Cassini's propulsion system at Saturn in the trajectory correction maneuvers on May 27 and June 16 and for orbit insertion on June 30—7 years after launch—is the most recent example. HRVDM/HDV's propulsion system will experience similar long-term storage and operational conditions and presents a similar challenge in that the most critical performance requirement—successful deorbit and controlled entry—cannot be accomplished until many years after launch. Specifically, GSFC requires full functionality after 7 years on orbit (10 years including shelf life). Meeting such a mandate requires an intimate understanding of degradation-type failures and a robust design resistant to thermal cycles, radiation, and other aging mechanisms.

Part selection, thermal control, radiation shielding, and fault protection are all critical to mitigating these life-limiting risks. On medium and high-risk items, we perform accelerated life testing or trends analyses to reduce uncertainty in component lifetime whenever possible. If new information becomes available about component lifetimes—as in the case of Star Tracker power supplies on the Genesis program, for example, which were found to be susceptible to enhanced low-dose-rate sensitivity (ELDRS) radiation effects—we actively requalify all affected parts for the required margins. (Genesis recertified its power supplies on the new degradation models.)

Even with mitigation strategies and margins in place, some items may be at risk for premature aging due to accumulation of calendar time, exposure, or duty cycles. Reliability Engineering will track any items whose expected lifetimes are shorter than half the design life on a Limited-Life List, a subset of the larger Critical Item List, and ensures that mitigation plans are developed. Limited-life items may be identified from accelerated life tests, historical performance, trends analysis, or by other. Atomic oxygen, solar radiation, extreme temperatures, thermal cycling, wear and fatigue will be used to identify limited-life thermal control surfaces and structural items. Items such as batteries, compressors, seals, bearings, valves, reaction wheels, gyros, and actuators will be evaluated when aging, wear, fatigue and lubricant degradation may limit their life. The Limited-Life List includes records of the cumulative stress (time and/or cycles) on limited-life items along with the project activities (testing, storage, transport) that cause the stress. The use of an item whose expected life is less than its mission design life must be approved by GSFC by means of a waiver.

To date, we have identified few critical limited-life issues on the HRVDM/HDV. Risks of degradation and wear-out are mitigated by radiation shielding, a hermetically sealed prop system, benign dormancy during science ops, and other safeguards. Possible (but low-risk) candidates for the limited-life list include the Li-ion batteries, fully expected to deliver a large energy margin but lacking a long history; and solar arrays, which exhibit a steady and well-known degradation profile.

4.10 Preliminary System Fault Tree Model

Reliability Engineering is working to map system-wide failure logic for use in our PRA. We include here for illustration excerpts from a fault tree model of the HRVDM (the HDV will be largely a subset) implemented in SAPHIRE. Our model lends itself naturally to hierarchical decomposition. At the mission level (not shown), we consider separately each distinct phase of the mission from orbit insertion to deorbit. The module and systems levels, shown in Figure 4.10-1, begin to decompose the spacecraft by function for each phase at the mission level. Figure 4.10-2 shows the expanded tree for the GN&C events, demonstrating the complicated failure logic of the thruster and sensor suites. In Figure 4.10-3, we show the failure (or unavailability) event for an individual piece of equipment—in this case, a non-functioning thruster—indicating either a failure of the item itself or an upstream failure that inhibits critical inputs to the item.

These partially populated trees currently omit some of the complexity we will eventually model. Higher-fidelity models, developed for inclusion in the FPDD at CDR, will better capture functional dependencies, and will include event trees to encode the time-dependent behavior of the system (such as the switching in of particular sensors that must function at different times). Software, human error, and dormancy modeling present additional challenges.

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5 SOFTWARE ASSURANCE REQUIREMENTS

Our Software quality assurance requirements exceeds ISO 9000-3

- Process compliant with SEI CMM Level 3
- Lockheed Martin's standard SW process Level 3 compliant specified entry and exit criteria for each SW domain
- Corrective action process specified in SW Product Management domain
- Inspection and testing performed by SW engineering by preparing a requirements traceability verification matrix

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This section provides an overview of the Software Assurance Process to be used on HRVDM/HDV. The full details of the Software Assurance Program are provided in the separate Software Management Plan required by DID SW-01.

5.1 General

LMSSC is currently certified to ISO 9001:2000 and AS9100 (pending) by a third party registrar, BSI (British Standards Institution). An SEI accredited assessor assessed LMSSC at SEI Level 3 in 1999 in a CMM Based Assessment for Internal Process Implementation (CBA/IPI) lead.

Lockheed Martin Software (S/W) Quality Engineering organization has a set of practices that meet and exceed the requirements of AS9100 and ISO 9001:2000. The S/W Management Plan (SQPP) references the LMMSC Standard S/W Process, which defines entry and exit criteria for each element of each S/W Development Domain. This process is compliant with the S/W Engineering Institutes Capability Maturity Model Level 3 and exceeds the level specified by ISO 9000-3.

5.2 Software Assurance

Lockheed Martin will document and implement a Software Assurance program in accordance with DID SW-01 and common LMSSC Software Quality Assurance practices, to address software assurance disciplines and functions for all flight and ground system software. The software assurance program applies to software and firmware (including PROMs, EEPROMS, and FPGAs) developed or reused under this contract, including Government off-the-shelf (GOTS) software, modified off-the-shelf (MOTS) software, and commercial off-the-shelf (COTS) software when included in a NASA system.

5.2.1 Software Safety

System Safety Analyses is conducted to identify any safety critical hardware components that are controlled by software. If any software component is identified as safety critical, a software safety program is conducted on that component that complies with NASA-STD-8719.13 "Software Safety Standard". The software safety analysis begins with the Preliminary Hazard Analysis produced by System Safety. Software requirements to control hazards applicable to software are identified during the safety analysis process. The software safety analysis process continues through the product life cycle to address product configuration changes.

Software Product Assurance monitors the development and testing of software ensuring the software requirements are incorporated into the software products. Test anomalies are corrected and managed by documented processes. Software configuration is controlled to ensure the product built and tested to the requirements performs in accordance with the requirements.

Software modules linked to an identified hazard are verified for compliance to software safety requirements, e.g., EWR 127-1 Section 3.16, “Computing Systems and Software.” In addition, a

Functional Failure Modes and Effects Analysis to detect potential faults that can escape detection in test are performed using the methodology used on MRO.

5.2.2 Verification and Validation

Lockheed Martin has implemented standard processes for Verification and Validation (V&V) that ensure that software being developed or maintained satisfies functional, performance, and other requirements at each stage of the development process and that each phase of the development process yields the right product. Part of V&V process is the generation of a Software Requirements Verification Matrix that is reviewed by Software Quality Assurance and maintained under configuration control. This matrix documents the flow-down of each requirement to the test case and test method used to verify compliance and the test results. The matrix will be made available to GSFC upon request.

V&V activities performed during the development process include the following:

1. Analysis of system and software requirements allocation, verifiability, testability, completeness and consistency (including analysis of test requirements)
2. Interface analysis (requirements and design levels)
3. Design and code analyses
4. Walkthroughs and/or inspections (i.e., engineering peer reviews)
5. Formal Reviews
6. Documented test plans and procedures
7. Test planning, execution, and reporting.

5.2.3 Independent Verification and Validation

The procedures for facilitating interaction with IV&V agents are given in Lockheed Martin's Standard Software Process.

Software management defines the mechanism for interfacing and communicating with IV&V agents. The prerequisite is that independent verification and validation (IV&V) of the S/W product(s) is required by the contract, and that the IV&V agent has been identified. The task is described as follows:

1. Define mechanisms for interfacing with the IV&V agent
2. Identify reviews, audits and tests to be conducted by the IV&V agent, as applicable
3. Establish points of contact with IV&V agents
4. Define any IV&V facility and support requirements
5. Document IV&V interface mechanisms for incorporation into the S/W Development Plan.

Mechanisms for interfacing with IV&V agents are agreed to by S/W management, the customer, IV&V agents and other affected organizations. The defined mechanisms are incorporated into the S/W Development Plan. This activity is in the establishment of S/W development planning, project tracking and oversight, and the performance of review activities.

S/W management communicates with the customer, associate contractors, IV&V agents, etc., as necessary. Status and reporting interfaces between the S/W team and external organizations are defined and agreed to. In addition, S/W management implements and maintains the mechanisms for interfacing to and communicating with the customer, associate contractors, and the IV&V agent (mechanisms can include electronic access to information, giving or accepting direction, providing or accepting status, escalating issues, and establishing points-of-contact).

S/W management engages the organization's participation in the following activities:

- Technical and management reviews requiring S/W team support in accordance with established mechanisms
- Status reviews and/or formal reviews of integration/testing required between the S/W team and each associate contractor
- Identified reviews, audits and tests to be conducted by the IV&V agent, as applicable
- Coordinate participation in reviews and other meetings with other affected groups
- Identify new risk items and actions required.

If deemed obligatory by IV&V findings, the S/W organization performs replanning as necessary.

Support of the IV&V activity ceases when the contract terminates or the interfacing mechanism is no longer required. The assessments and updates are available for GSFC review and are presented at PDR and CDR. The presentations shall include a summary of how the analysis was used to perform design tradeoffs or how the results were taken into consideration when making design or risk management decisions.

5.3 Reviews

5.3.1 Software Reviews

Lockheed Martin will conduct the formal software reviews required by the MAR as well as any additional reviews required by our internal Software Management Process as defined in DID SW-01. The specific reviews required by the MAR are as follows:

- Software Requirements Review (SWRR).
- Software Preliminary Design Review (SWPDR)
- Software Critical Design Review (SWCDR)
- Software Test Readiness Review (SWTRR)
- Software Acceptance Review (SWAR).

If software is addressed as part of the formal system-level reviews (e.g., SRR, PDR, or CDR), the LM Team shall adhere to the review criteria provided by the GSFC Systems Review Office as discussed in Section 8 of this plan.

5.3.2 Engineering Peer Reviews

Lockheed Martin's standard process includes implementation of engineering peer reviews (e.g., design walkthroughs or code inspections) throughout the software development lifecycle to identify and resolve concerns prior to formal system/subsystem level reviews. These reviews will be commensurate with the scope, complexity, and acceptable risk of the software system/product as defined in the Software Management Plan required by DID SW-01.

Action items or Requests for Action (RFAs) from engineering peer reviews are recorded, maintained, and tracked throughout the development lifecycle per existing Lockheed Martin procedures.

5.4 Software Configuration Management

This activity defines the tasks for controlling the formal software baselines and the developmental product configuration, full details will be addressed in DRD SW-01. Software configuration management begins with the establishment of the allocated baseline, which identifies the software items that are formally managed in coordination with the Program Configuration Control Board and the customer.

The software configuration management (SCM) baseline is established throughout the development lifecycle. At the beginning of the software architecture design activity, Software Configuration Management identifies and establishes a developmental product configuration for each of the software items, which are managed internally as the developmental product configuration evolves into what subsequently becomes the formally managed product baseline. The developmental product configuration consists of the architecture and detailed design and the source code (software units), which are incorporated into the developmental product configuration as they become available and are released to the Software Development Library for control.

The Software Configuration Management Specialist accepts software units from the software developers as they are released for control and to be compiled and linked into executable code builds for integration and testing at all levels beyond unit testing through system qualification testing. Software products are placed under configuration management immediately after the successful conclusion of each review. Informal control is used for preliminary versions of all products before it is placed under the formal SCM system. SCM performs periodic audits to ensure the integrity of the baselines and provide status accounting to reflect the "as-built" configuration.

Upon completion of all formal testing, the conduct of any formal configuration audits (i.e., functional and physical configuration audits), and the release of the deliverables, Software Configuration Management prepares source code, the installation build (executable code) and associated documentation for transfer to the product baseline. A software configuration management task generally involves establishing software product baselines or software product developmental baselines.

Any change classification and/or impact assessments that result in Class 1 (defined as those that affect system requirements, software requirements, system safety, cost, schedule, and external interfaces) or Class 2 changes constitute part of a CCB activity. The GSFC Project may elect to assign a project representative as co-chair of the SWCCB. The GSFC co-chair's concurrence with classification is sufficient to proceed with Class 2 changes, while Class 1 changes are forwarded to GSFC for disposition and approval.

5.5 Software Problem Reporting and Corrective Action

Lockheed Martin has developed an Organizational Standard Process (OSP) for Software Problem Reporting and Corrective Action (3.6-T1-ProdAssr-1.2-P) that addresses reporting, analyzing and correcting software nonconformances throughout the development lifecycle. The system and database shall be accessible remotely via the web by approved HRVDM/HDV Project representatives.

Upon establishment of a software baseline in accordance with Section 5.4, software nonconformances are reported and dispositioned as described in Section 1.5.3 of this plan. Lockheed Martin's nonconformance reporting system provides for linkage, traceability, or cross-referencing of information with the Software Problem Reporting system.

5.6 GFE, Existing and Purchased Software

The LM Team will ensure that any commercial, reusable or Government provided software or firmware meets the functional, performance and interface requirements placed upon it. Lockheed Martin will ensure that the software meets applicable standards, including those for design, code and documentation, or will secure an HRVDM/HDV Project waiver to those standards.

5.7 Software Assurance Status Reporting

Lockheed Martin will provide the monthly status reports required by DRD SW-16. With GSFC approval, the LM Team will leverage existing metrics and reports required by our internal processes to satisfy customer requirements.

5.8 NASA Surveillance of Software Development

Lockheed Martin welcomes NASA representatives and/or their designate to perform surveillance activities throughout the entire software development cycle.

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7 RISK MANAGEMENT REQUIREMENTS

A Risk Management Plan will be prepared to define the overall qualitative and quantitative approach to risk management on the HRVDM/HDV program. The general approach is described in Section C-2 of the proposal and will follow the guidance of NPG 8000.4, "Risk Management Procedures and Guidelines. Our risk management process consists of performing the steps of risk identification, analysis, planning, tracking, and control consistent with the NASA Continuous Risk Management process.

7.1 General Requirements

The Risk Management Plan complies with the following:

NPG 8000.4, *Risk Management Procedures and Guidelines,* April 25, 2002, Office of Mission and Safety Assurance, NASA Headquarters, Washington, D.C.

7.2 Probabilistic Risk Assessment

Probabilistic Risk Assessment (PRA) techniques will be used in some cases to determine the probability of particular risk events in support of the Risk Analysis process described in Section C-2.1.2 of the proposal. Risk management works with the Reliability Assurance organization to create and maintain a comprehensive PRA. Refer to Section 4.2 of this Mission Assurance Plan for a more detailed description of this technique.

7.3 Risk List

A concern with the development of any program risk list is whether the set of risks is comprehensive or complete. The Risk Identification process, discussed in Section C-2.1.1 of the proposal, indicates that numerous techniques are used for identifying candidate risks and that these techniques vary, depending on the stage in the program lifecycle. Initial risk identification on this program was performed by conducting interviews with subject matter experts on all systems associated with the HRVDM/HDV, and by reviewing lessons learned from other programs. As added assurance of the completeness of the initial risk list, an alternate approach for identifying candidate risks, focusing on risk areas and WBS elements, was developed (see Fig. 7.3-1). This alternate evaluation expanded the risk areas investigated to include environmental, safety, new technology, occupational health, security, and export control in addition to the traditional risk areas of cost, schedule, and technical performance. Each major WBS element was examined for candidate risks in each of the nine risk areas. The candidate risks generated by this process are general risks rather than being specific, detailed statements of risk. The resulting comprehensive set of general, candidate risks is used as an additional source for risk identification for the program. The matrix of candidate risks is preliminary and will be finalized following contract award.

Based on the HST Robotic Servicing Mission Concept Review presented by GSFC, the subject-matter expert interview process, management meetings, and the candidate risks found in Fig. 7.3-1 and 7.3-2, a set of risks were identified for the program. The currently identified risks to the HRVDM/HDV program and their mitigation strategies are presented in Fig. 7.3-3. The risk list indicates both the current risk level and the risk level expected by PDR. Note that several of the High Risks identified by GSFC in their Concept Review are already mitigated to lower risk levels based on the team selection and the design work performed in the development of this proposal.

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8 TECHNICAL REVIEW REQUIREMENTS

The LM Team review process builds progressively from detailed internal peer reviews to formal element and segment level reviews. Formal reviews, included as key events in our event-based master plan are triggered when success criteria for significant accomplishments are met.

Peer reviews leverage the LM Team experience base and are performed in accordance with process document 3.5.2-T1-MSuccess-1.2-P. Peer reviews are used for identifying and removing defects from work products early in the development cycle, generally prior to product baseline. They involve a methodical examination of work products by peers of an author to identify defects, areas where changes are needed and significant risk areas. Work products that will undergo peer review are identified in the planning process and scheduled as part of the planning activities. The peer review process supports Lockheed Martin goals of meeting customer quality needs and continual process improvement.

8.1 General

Lockheed Martin has implemented a process document, 3.5.2-T1-MSuccess-1.3-P, that controls the review process and is based on company best practices and the IEP requirements. The process ensures that the IPTs:

- Develop and organize material for oral presentation to the GSFC review team and ensure copies of the presentation material are available at each review
- Support splinter review meetings resulting from the review
- Produce written responses to recommendations and action items resulting from the review
- Summarize, as appropriate, the results of the LM Team reviews at the component and subsystem level.

8.2 Reviews

The LM Team supports the formal GSFC reviews required by the contract, specifically:

- System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR
- Mission Operations Review (MOR)
- Preenvironmental Review (PER) or Test Readiness Review (TRR)
- Flight Operations Review (FOR)
- Preship Review (PSR)
- Launch Readiness Review (LRR).

In addition, Lockheed Martin will implement a series of reviews required by our company processes including Independent Readiness Reviews and Presidents Mission Success Reviews prior to key milestones. GSFC will be invited to attend.

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9 DESIGN VERIFICATION REQUIREMENTS

9.1 General

The Lockheed Martin team verifies the performance of the HRVDM system through a comprehensive method designed to find any problems early in the program, creating maximum schedule availability to rectify shortfalls. Requirement compliance is crosschecked by verification at the lowest possible assembly, and then reverified at subsequent higher levels of assembly. Final checks are performed at the integrated DM/EM level at the GSFC. Since performance verification of certain components and subsystems must necessarily be verified prior to inclusion in system level tests, all components are operating and monitored during environmental and other system level tests as practical.

Verification methods used by the Lockheed Martin team include performance tests, whereby performance parameters are measured under flight-like environmental conditions; functional demonstrations, where the parameters are measured in laboratory conditions and analysis is performed to extrapolate the results to flight conditions; analytical investigations, where the parameters are analytically shown to be in compliance; and through physical measurements, which measure physical characteristics of the DM. The preferred method of verification is performance test since it replicates performance under flight conditions. For parameters where this is not feasibly performed, the other listed methods of verification are used, coupled with an analytical evaluation to extrapolate the results to flight conditions.

Another aspect of the verification program is to provide environmental stress screening designed to uncover workmanship defects. In this, critical elements of the system are subjected to environments more severe than expected in flight so as to demonstrate performance margins and provide additional confidence in mission success.

The total verification program also includes the development of models to represent the system hardware. These models are included in end-to-end tests and simulations to show that the total system will perform to specification. Adequacy of the models is verified through component and subsystem tests coupled with analyses, alignments and calibrations as necessary.

Lockheed Martin implements the GEVS-SE requirements in concert with our internal verification process (2.3.8-T1-SE-1-P) that was developed using corporate Best Practices and the LM-IEP.

9.2 Documentation Requirements

The documents required by Lockheed Martin's Verification Process (2.3.8-T1-SE-1-P) combine several of the elements required by the MAR and will be submitted to GSFC for approval as required by the MAR and the DRDs. For example, the Verification Process requires that detailed plans be developed for each verification method (i.e., Test, Demonstration, Analysis and Inspection). Each verification plan documents the following:

- Requirements to be verified, commonly in the form of lower level matrices derived from the system verification plan's requirements matrix
- Success Criteria
- Expected results, required tolerances for the verification method providing those results, and success criteria

- Simulation, analysis and assessment tools and methodology
- Demonstration/test configuration set-up
- Special equipment, facilities and databases for each verification activity.

Therefore, it is expected that the required test and verification plan(s) would satisfy the requirements for an environmental verification plan and environmental verification matrix.

9.2.1 System Performance Verification Plan

The Lockheed Martin team documents the tasks and methods used to verify the performance of the HRVDM against all mission requirements. Included in this plan are the subsystem requirements and the methodology used for verification. Identification of the performance verification method for each requirement, along with any justification for methods other than systems level test, is included. Also included is an assessment of any limitations in the ability to directly verify any requirement to include any analysis or supplemental tests performed to complete the verification process. This includes a risk assessment to quantify potential program impacts. The system Performance Verification Plan will be developed in accordance with 2.3.8-T1-SE-1-P as augmented by GEVS-SE , the MAR and DRD (DM/DV-02) requirements.

9.2.2 Environmental Verification Plan

The Environmental Verification Plan is prepared to prescribe tests and analyses necessary to ensure that the hardware and software complies with the environmental verification requirements. This plan includes a description of the overall approach along with descriptions of each test to be performed. The test descriptions include item configuration, test objectives, facilities, special test equipment, safety considerations, test profiles and functional operations. It also includes a description of personnel responsibilities in this process along with any required procedures and test reports. It also describes any potential retest actions, along with an assessment of validity of previous environmental test activities. Any limitations to the environmental test program that preclude verification by test are described, along with supporting analyses, risk assessments and alternative test actions are also included.

The test and demonstration verification plan(s) required by 2.3.8-T1-SE-1-P will address the requirements of the Environmental Verification Plan. The environmental portions of the plan will be based on 2.3.8.1-T1-TE-3-P, Test Requirements Process (TRP) and GEVS-SE.

9.2.3 *System Performance Verification Matrix*

The System Performance Verification Matrix is maintained that provides a summary of all tests performed to verify environmental compliance. All verification activities, starting at component level and continuing through DM/EM systems level, are identified along with the method used to perform the verification. This matrix is maintained so as to provide a current summary of all verification activities and is included in all system review data packages.

9.2.4 Environmental Test Matrix

The Environmental Test Matrix is maintained as an adjunct to the System Performance Verification Matrix. It summarizes all environmental tests performed on each component and subsystem along with DM level and combined DM/EM levels. This matrix is maintained so as to depict a current summary of all environmental test activities and is included in all system review data packages.

9.2.5 Environmental Verification Specification

Specific environmental parameters that each system component undergoes to verify compliance with performance requirements are defined in the Environmental Verification Specification. Special conditions, such as the interaction with the launch vehicle, are taken into account. The Environmental Verification Specification will be a part of the Verification Requirement Documentation specified in 2.3.8-T1-SE-1-P, as augmented by GEVS-SE and 2.3.8.1-T1-TE-3-P, Test Requirements Process (TRP).

9.2.6 Performance Verification Procedures

Performance verification procedures are generated in accordance with 2.3.8-T1-SE-1-P, for each component, subsystem, and system level test described in the verification plan. This procedure describes the test configuration, defines the test equipment required and provides a step-by-step description of the actions performed to verify compliance. Details, such as pass/fail criteria, test parameters, data collection, quality control checkpoints and reporting requirements are included. Safety concerns are addressed along with any special considerations, such as contamination.

9.2.7 Verification Reports

Verification Reports are generated for each verification activity in accordance with 2.3.8-T1-SE-1-P. Issues covered in this report include the degree to which the objectives were accomplished, an assessment of the math model's validity, and any other significant results. As run procedures and actual test data are retained for review.

9.2.8 System Performance Verification Report

The System Verification Report is prepared at the conclusion of all verification activities. It summarizes all measured (or computed) performance parameters and provides a comparison to specified performance values for all components, subsystems, DM and the combined DM/EM system.

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10 WORKMANSHIP STANDARDS

Lockheed Martin's design and manufacturing standards incorporate best practices across business and customer bases

- Figure of Merit (FOM) tool used on HST to evaluate solder joint reliability for SMT designs
- Strict controls in place for interface of flight and non-flight hardware during test operations
- PWB coupons shall be submitted to GSFC for approval per procedures developed on HST, Terra and Landsat 7

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Lockheed Martin has implemented a series of workmanship standards based on industry standards (IPC), NASA and Military Specifications as well as "best practices" from across Lockheed Martin. The in-house workmanship standards meet the NASA-STD-8739 series and have been used successfully on NASA and Military spacecraft.

10.1 Applicable Documents

Applicable documents are provided in Appendix 1.

10.2 Design

10.2.1 Printed Wiring Boards

Lockheed Martin has implemented design and manufacturing requirements for printed wiring board (PWB)/circuit card assemblies (CCAs) that was created by a multifunctional team (design engineering, manufacturing, sourcing, quality, etc.) composed of representatives from business units across Lockheed Martin. The design and manufacturing standards (EPI 100-02) is based upon IPC-2221, IPC-2222 and IPC-2223 as well as "best practices" from Lockheed Martin sites. "Best Practice" information is clearly identified in the document to distinguish it from the IPC requirements. The flight PWB designs will not include features that prevent the finished boards from complying with the Class 3 requirements of EPI 100-02.

Lockheed Martin also uses a Figure of Merit (FOM) analysis tool that is based on the Engelmaier equation to predict solder joint reliability of SMT components. The FOM is based upon accelerated life test data that was used to characterize the Engelmaier equation's "non-ideal" factor that accounts for the manufacturing process. The FOM was used on the HST diode box assemblies and shall be used to ensure the HRVDM/HDV designs meet their life requirements.

10.2.2 Assemblies

The design considerations of the NASA workmanship standards shall be reviewed as part of the peer review process within the IPTs.

10.2.3 Ground Data Systems that Interface with Space Flight Hardware

Connector savers are fabricated/procured using space flight parts, materials and processes. Where connector savers are not used, the mating hardware shall be of flight materials and fabricated per flight processes.

All equipment that resides within environmental test chambers is evaluated for compatibility with the unit-under-test (UUT) as well as with the environment as part of the design process for the test equipment. Ground support equipment (GSE) materials that are exposed to thermal vacuum environment during ground test are selected with consideration of outgassing characteristics. GSE materials that do not meet the outgassing levels are substituted or preconditioned in a separate thermal vacuum bakeout to meet requirements prior to use during HRVDM/HDV thermal vacuum testing to avoid cross-contamination to flight hardware.

Any tests that use placeholders (i.e., non-flight items or non-end items) are subject to strict controls in accordance with 3.6-T1-PA-61.1-P, PIRS-Based Control and Disposition of Nonconforming Hardware.

10.3 Workmanship Requirements

10.3.1 Training and Certification

All personnel who manufacture, inspect, test, or otherwise process electronic hardware are trained prior to handling any hardware. Required training and certification is defined and implemented (including ESD, see Section 14) in accordance with LM's detailed process documentation. Training and certification records are maintained in the Lockheed Martin Data Systems.

10.3.2 Flight and Harsh Environment Ground Systems Workmanship

10.3.2.1 Printed Wiring Boards

All flight PWBs are manufactured in accordance with Class 3 requirements per EPI 100-02, which meets or exceeds the GSFC requirements. All PWB coupons for the HRVDM/HDV program shall be submitted to GSFC Materials Engineering Branch or to a GSFC approved laboratory for evaluation. GSFC approval is obtained prior to population of the flight PWBs. Lockheed Martin has implemented this coupon submittal approach on past GSFC programs such as HST, Terra, SXI and Landsat 7 with great success.

10.3.2.2 Assemblies

Assemblies shall be fabricated to existing LM standards that have been developed to meet NASA standards as well as IPC and best practices from across Lockheed Martin Businesses.

10.4 New or Advanced Materials and Packaging Technologies

New or advanced packaging technologies (e.g., multichip modules (MCMs), stacked memories, chip on board, ball grid array (BGA)) are reviewed and approved for the intended application through the Parts Control Board and documented in the Parts Lists as defined in Section 11.2.3 of this plan.

10.5 Hardware Handling

Product Assurance ensures handling requirements are implemented during all phrases of the HRVDM/HDV Program's implementation. System Safety ensures that critical hardware design; drawings, procedures and associated handling equipment design features are incorporated in critical hardware movement to protect hardware. In addition, Lockheed Martin has implemented several improvements listed below as a result of company best practices and lessons learned from recent incidents such as TIROS:

- Functional Failure Modes and Effects Analysis (FFMEA) are performed for all equipment involved in critical product operations handling procedures are validated prior to use
- Error Prevention training certification that provides tools to personnel to avoid human errors, and these tools are built into the test conduct process.
- Training and certification of Test Conductors and Product Assurance personnel.

- Implementation of Pretask briefings (Huddles)
- Inspection pre and post movement.

The ESD control procedures are defined in Section 14, while Contamination sensitive handling is addressed in Section 13.6.

11 PARTS REQUIREMENTS

Lockheed Martin's PMPCB process has been used successfully on previous NASA programs

- Web-based PMPCB process and associated parts lists developed and implemented on A2100 program
- Subcontractor listings incorporated into on-line database
- Realtime database with remote access facilitates IPT/subcontractor/GSFC interface

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11.1 Introduction

General—The LM Team shall implement a Parts, Materials and Process Control Board (PMPCB) process that has been used successfully on previous NASA programs. For HRVDM/HDV the process makes extensive use of web-based based databases to provide seamless access among HRVDM/HDV team members, subcontractors and GSFC. Lockheed Martin has implemented Web-based PMPCB systems on past programs as shown in Fig. 11.1-1. Subcontractor Parts Control requirements are flowed down via a separate Parts Requirements document that is implemented in the Statement of Work.

11.2 Parts and Material Control Board

The LM Team shall establish and use a PMPCB to oversee in-house and subcontractor parts/supplier selection and management. The primary objective of the PMPCB is to ensure that in-house and subcontractor supplier/part selections are appropriate for HRVDM/HDV program requirements and are consistent with the LM Team parts philosophy and subcontractor program standards. A Parts Engineer shall be assigned as a single-point contact for all actions and resolution of parts problems occurring across Product teams.

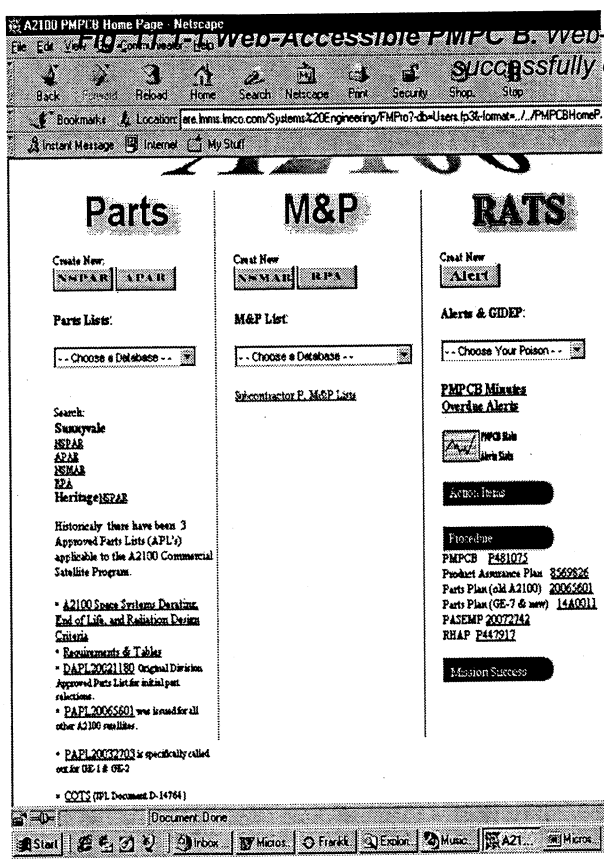

Fig. 11.1-1. Web-Accessible PMPCB. Web-Based PMPCB systems have been implemented successfully on past programs

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The subcontractor's PMPCB is to implement a parts program internally that adheres to the objectives listed herein. Use of a subcontractor's existing proven process is desirable. The subcontractor should be capable of showing their process is under adequate control to achieve Mission Success Requirements. The subcontractors PMPCB Chairpersons provide the communication link with the Lockheed Martin PMPCB. The subcontractor's PMPCB process shall be included as part of their PCP submittal. Subcontractor PMPCB meeting minutes shall be submitted to the Lockheed Martin PMPCB within 5 business days of their meeting. Lockheed Martin PMPCB reserves the right to audit all subcontractors for compliance to their PCP.

11.2.1 PMPCB Meetings

PMPCB meetings are convened on a regular basis or as needed. Meeting minutes or records shall be maintained by the LM Team to document all decisions made and a copy provided to GSFC within five business days of convening the meeting. GSFC retains the right to overturn decisions involving non-conformances within five days after receipt of meeting minutes. PMPCB activities may be audited by GSFC on a periodic basis to assess conformance to the PCP.

Parts selected that are not listed on the NASA Parts Selection List (NPSL), PPL-21 or MIL-STD-975 shall be identified on a Parts Identification List (PIL) and submitted to the subcontractor's PMPCB. The Lockheed Martin PMPCB shall give final approval. The subcontractor's representative(s) participate in the Lockheed Martin level PMPCB meetings at which time the nonconforming items are reviewed and acted upon.

Part issues that cannot be resolved by the PMPCB shall be elevated to the HST SAM and HRVDM/HDV Project Manager for disposition.

11.2.2 PMPCB Membership

The PMPCB membership shall include a Product Assurance Representative as well as members from major subcontractors as required. The purpose of a Product Assurance representative involvement is to assure that the PMPCB functions in accordance with Lockheed Martin procedures and contractual quality requirements. The PMPCB shall consist of the following members:

- Product Assurance Representative (Chairperson)
- Specialty Engineering Representative (Parts or Materials Engineers) Co-Chair
- Subcontractor Representative (as required)
- GSFC Parts/Materials Engineer
- GSFC Radiation Engineer (for EEE parts)
- Responsible Design Engineer (as required).

The Chairperson of the PMPCB may designate other members. Each subcontractor member shall have the authority to commit their company to PMPCB decisions and actions that are within the scope of the PMPCB and the applicable contract. Other technical support representatives from the subcontractors and Lockheed Martin disciplines may attend as consultants when required.

11.3 Parts Selection and Processing

All parts shall be selected and processed in accordance with the GSFC 311-INST-002 Instructions for EEE Parts Selection, Screening. Qualification and Derating for part quality level 1. For those parts not readily available as quality level 1 but are available at quality level 2, approval shall be obtained from the PMPCB on a case-by-case basis and the required screening and qualification tests required by the PMPCB shall be implemented. Parts selected from the NPSL, PPL-21 and MIL-STD-975 (quality level 1) and have met all 311-INST-002 criteria are considered preferred. The Lockheed Martin PMPCB may approve such parts, provided all mission application requirements (performance, derating, radiation, etc.) are met. All other EEE parts shall be selected, manufactured, processed, screened, and qualified, as a minimum, in the same manner as the nearest applicable Quality Level 1 device(s) to the requirements of 311-INST-002.

Lockheed Martin Systems Engineering may recommend that some previously designed products that used parts with less than Quality Level 1 be considered for acceptance at a lower quality level as part of the Inheritance Review process discussed in Section 1.2. For such cases, Systems Engineering will provide a written recommendation to the PMCB indicating what effects, if any on the mission reliability requirements resulting from the lower parts quality level. The PMPCB will review the Systems Engineering recommendation, the proposed parts list and the expected applications and environment and provide their recommended disposition of the parts. Any disputes between the Systems Engineering and PMPCB recommendations will be documented as a request for waiver and processed through the Project with both recommendations attached to the waiver for supporting information.

The requirements of 311-INST-002 may be further tailored as appropriate to specific HRVDM/HDV mission requirements. The LM Team's internal selection and processing documentation may be used to define these requirements with PMPCB approval. The requirements then become the established criteria for parts selection, testing, and approval for the duration of the project, and shall be documented in the Parts Control Plan.

A source control drawing (SCD) or and Altered Item Drawing (AID) shall be required for EEE parts selected, by the LM Team, that are not listed on the NPSL, PPL-21 or MIL-STD-975 when required by the Parts Engineer. The SCD or AID shall be written in accordance with GSFC 311-INST-002 Quality Level 1 guidelines as a minimum. The SCD or AID shall fully identify the part being procured and shall include physical, mechanical, electrical, screening, and environmental test requirements (including test conditions, failure criteria, and lot rejection criteria), and quality assurance provisions necessary to control manufacturing and acceptance if applicable. For lot acceptance and rejection, the Percentage of Defectives Allowable (PDA), shall be in accordance with that prescribed in the closest military part specification. All non-preferred parts shall be documented on a PIL and submitted to the PMPCB for approval.

11.4 Custom Devices

In addition to applicable requirements of 311-INST-002, custom microcircuits, hybrid microcircuits, detectors, MCM, ASIC, etc., planned for use shall be subjected to a design review. The review may be conducted as part of the PMPCB activity. The design review shall address, at a minimum, derating of elements, method used to assure each element reliability, assembly process and materials, and method for assuring adequate thermal matching of materials. Assembly travelers, screening travelers and qualification test plans shall be reviewed and approved by Lockheed Martin or subcontractor's parts engineer prior to the processing of any flight production lot. The responsible parts engineer will perform source inspection and will perform a precap visual on all custom microcircuits, hybrid microcircuits, MCM, ASIC, etc. A customer source inspection may also be required as determined by the PCB.

11.5 Plastic Encapsulated Microcircuits (PEMS)

The use of Plastic Encapsulated Microcircuits and plastic semi-conductors is discouraged. However, when use is necessary to achieve unique requirements that cannot be found in hermetic high reliability microcircuits, plastic encapsulated parts, must meet the requirements of NASA GSFC Supplement to GFSC EEE-INST-002. The PMPCB shall review the procurement specification for appropriate testing, and also review application, procurement and storage processes for the plastic encapsulated part(s) to assure that all aspects of the GSFC policy have been met. The PMPCB may grant Preliminary Approval when the GSFC requirements have been met. Final approval for the use of the PEM(s) shall be obtained from the HRVDM/HDV Program Office.

11.6 Derating

All EEE parts shall be used in accordance with the derating guidelines of GFSC EEE-INST-002. The LM Team's derating policy may be used in place of the GSFC guidelines after submittal for approval. The LM Team shall maintain documentation on parts derating analysis and make it available for GSFC review upon request. Parts that cannot be used within the derating guidelines shall be submitted to the PCB for approval. All approved part applications that do not meet the derating criteria are listed on the Critical Items List. Compliance with parts derating shall be demonstrated at spacecraft qualification temperatures.

11.7 Radiation Hardness

The LM Team maintains documentation that demonstrates statistically that parts shall meet all critical electrical parameters after exposure to radiation of 2 times the use environment. This "use environment" is expressed as the total ionizing dose over the mission life behind 0.100 inch spherical aluminum shielding. The documentation must be applicable to the specific device (e.g., design, technology, process line, and processes) and validated by device radiation specialists.

Radiation Lot Acceptance Testing (RLAT) is required for parts susceptible to radiation induced degradation <2 times the use environment if such degradation has a negative impact on circuit performance. This RLAT testing must be adequate to ensure that devices used from the lot shall meet all design critical requirements after radiation to the end use application. The lot acceptance may be done by appropriate correlation testing, guard-band testing, etc. or by radiation exposure of samples from each lot.

The system electronics radiation environment consists of Trapped Protons and Electrons as defined in the NNG0461779R and the NASA AP-8 and AE-8 models. The Single Event environment is defined in the NRL CREME96 Heavy Ion and Solar Event models and in the AP-8 SAA proton spectral flux model. These models will be applied combined with Space Radiation V5.0 or NOVICE 3_D Shielding analysis to derive exposure levels at electronics within the system. TID and SEE hardening will be accomplished through a combination of piece part selection, tolerant circuit designs and flight software SEE mitigation.

The specific radiation performance requirement for a part is a function of its location and application in the space vehicle. All parts are selected to perform their function in their intended application for a 2X mission radiation dose based on The Radiation Environment for the HRVDM/HDV Project, and any associated analyses. The PMPCB reviews the radiation susceptibility of each selected part against the end use application. Part qualification to the requirements in the following Sections may be based on technology or part number test data.

11.7.1 Total Ionizing Dose (TID) Including Enhanced Low Dose Rate (ELDR) Effects

Parts are selected to ensure their adequate performance in the application up to a dose of 2x the expected mission dose. Linear bipolar parts are assumed to be ELDR susceptible unless the parts have been successfully tested and shown to be insensitive.

11.7.2 Displacement Damage

All parts shall be evaluated for Displacement Damage sensitivity up to a dose of 2x the expected mission displacement damage dose. Potentially susceptible parts include but are not limited to optical devices, photo-detectors, charge-coupled devices, optocouplers, LEDs, laser diodes, and precision bipolar linear devices.

11.7.3 Single Event Effects

Parts that are susceptible to Single Event Effects shall be characterized for their particle-induced threshold where their circuit application dictates. Minimum SEE thresholds are established by the PMPCB for specific device/equipment application. The box level CPE or responsible subcontractor analyzes the consequences of single-event induced error modes to the part, circuit, subsystem, system and spacecraft. In particular, the analysis considers the consequences of Single Event Upset (SEU) or Single Event Transient (SET) in each application of the part. Parts susceptible to Single Event Latch up (SEL) will be avoided.

11.8 Part Analysis

11.8.1 Destructive Physical Analysis

A sample of each lot date code of microcircuits, hybrid microcircuits, EMI filters, relays, capacitors, oscillators, and semiconductor devices shall be subjected to a Destructive Physical Analysis (DPA) as determined by the PMPCB. All other parts may require a sample DPA if it is deemed necessary as indicated by failure history, GIDEP Alerts, or other reliability concerns. DPA tests, procedures, sample size and criteria shall be as specified in GSFC specification S-311-M-70, Destructive Physical Analysis. LMSCC and its subcontractor's procedures for DPA may be used in place of S-311-M-70 and shall be submitted for approval with the PCP. Variation to the DPA sample size requirements, due to part complexity, availability or cost, shall be determined and approved by the PMPCB on a case-by-case basis.

11.8.2 Failure Analysis

The LM Team ensures that root cause failure analysis is performed for each failure. Those that are isolated to EEE parts will be submitted to the PMPCB for review and approval of the failure report, supporting data, analyses, and photographs. If lot dependency is found, the assemblies using the suspect lot will be dispositioned through the nonconformance reporting system with coordination with the Mission Success organization as required.

11.9 Parts Age and Storage Control

All parts procured with date codes indicating that more than five (5) years have elapsed from the date of manufacture to date of procurement shall be subjected to a rescreen and sample DPA per PMPCB recommendation. Alternate test plans may be used as approved by the PMPCB on a case-by-case basis. Parts taken from user inventory older than 5 years do not require rescreen, provided they have been properly stored. Parts over 10 years from the date of manufacture to date of procurement or stored in other than controlled conditions where they are exposed to the elements or sources of contamination shall not be used.

11.10 Parts Used in off-the-Shelf Assemblies

Units or assemblies that are purchased as "off-the-shelf" hardware items shall be subjected to an evaluation of the parts used within them. The parts shall be evaluated for screening compliance to GSFC EEE-INST-002, established reliability level, and include a radiation analysis. Units may be required by the PMPCB to undergo modification for use of higher reliability parts or Radiation hardened parts. All parts shall be subject to PMPCB approval.

Modifications such as additional shielding for radiation effectiveness or replacing radiation soft parts for radiation hardened parts may be required and shall be subject to Radiation Effects approval.

11.11 Value Added Testing

The following value added tests provide for enhanced reliability of parts and will be implemented via source control or altered items drawings and summarized in the PAPL. Unless otherwise specified, testing shall be in accordance with the test methods referenced in GSFC EEE-INST-002.

11.11.1 Particle Impact Noise Detection (PIND)

All EEE parts with internal cavities (transistors, microcircuits, hybrids, relays and switches) are subjected to 100% PIND screening in accordance with MIL-STD-883, Method 2020, Condition “A” or a PMPCB approved equivalent. Any device failing this screen will be removed from the lot shall not be used in any flight application and the remainder of the parts will be considered to be acceptable.

11.11.2 Capacitors

11.11.2.1 Surge Current Screening for Tantalum Capacitors

All solid tantalum capacitors used in filtering applications shall be subjected to surge current screening. Chip devices (CWR06 for example) shall receive testing in accordance with MIL-PRF-55365 (+25°C only). This testing can be performed at the manufacturer’s facilities by adding an “A” suffix to the standard military part number. Leaded devices (M39003/01 for example) shall receive testing in accordance with MIL-PRF-39003/10.

11.11.2.2 Dielectric Screening for Ceramic Capacitors

Ceramic capacitors used in circuits at or below 10V shall be rated at 100V or greater except as follows. Each lot of capacitors rated below 100V, shall have samples subjected to Humidity Steady State Low Voltage testing (85°C and 85% relative humidity) in accordance with MIL-PRF-123 (12 piece sample for each lot/date code). Following humidity exposure, a Destructive Physical Analysis (DPA) shall be performed in accordance with MIL-PRF-123 (sample size per GSFC S-311-M-70, for each lot/date code) prior to acceptance.

11.11.3 Screening for Magnetic Components

Magnetic devices (transformers and inductors) shall be assembled and screened to the requirements of MIL-STD-981 (Design, Manufacturing and Quality Standards for Custom Electromagnetic Devices for Space Applications) for class S devices. Burn-in screening shall be considered based on vendor history, performance stability requirements, device complexity, and application criticality.

Simple toroidal coils with one layer of windings may be exempted from burn in unless required by the core manufacturer to stabilize its properties, and such decisions require PMPCB documentation and approval.

11.12 Parts List

The HRVDM/HDV Parts Lists shall include subcontractor listings and be Web-based to maximize accessibility by all members of the design team, including GSFC. The various parts lists described below may be combined into a single database that includes the fields shown in Fig. 11.12-1.

Field	Required Field for Parts List Type		
	ADPL	PAPL	ABPL
Item Number	X	X	X
Spacecraft Name	X	X	X
Instrument Name	X	X	X
Generic part Number	X	X	X
Procurement Part Number	X	X	X
Flight Part Number		X	X
Description	X	X	X
Package: Case Style and Number of Pins	X	X	X
Lot Date Code			X
Manufacturer	X	X	X
Cage Code	X	X	X
Distributor	X		
Additional Testing Required	X	X	
Quantity needed	X		X
Quantity Procured	X		
Radiation Hardness Evaluation: TID, Krads	X	X	X
Radiation Hardness Evaluation: SEL, MeV	X	X	X
Radiation Hardness Evaluation: SEU, MeV	X	X	X
Radiation Hardness Evaluation: Displacement Damage	X	X	X
Radiation Data Source: TID	X		
Radiation Data Source: SEE	X		
Notes	X		
PMCB Comments	X	X	
Approval Date	X	X	X
Box Identification	X	X	X
Part Location (Circuit Identifier)			X

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Fig. 11.12-1 Integrated web-based database captures data fields required for effective parts management program.

11.12.1 Program Approved Parts List (PAPL)

The Program Approved Parts List (PAPL) shall be the only source of approved parts for program flight hardware, and as such may contain parts not actually in flight design. Only parts that have been evaluated and approved by the PMPCB shall be listed in the PAPL. Parts must be approved for listing on the PAPL before initiation of procurement activity. The criteria for PAPL listing shall be based on 311-INST-002 and as specified herein. The PMPCB shall assure standardization and the maximum use of parts listed in the PAPL. The PAPL may be combined with the Parts Identification List (PIL) (see Section 11.12.2). This list shall be available via the Internet for GSFC review and approval as part of the PMPCB process.

11.12.2 Parts Identification List (PIL)

As opposed to the PAPL, the PIL shall list all parts planned for use in flight hardware, regardless of their approval status. The PIL shall include as a minimum the following information: part number, part name or description, manufacturer, manufacturer's generic part number, drawing number, specifications, comments as necessary to indicate problems, long lead times, additional testing imposed, application unique notes, etc. The initial PIL and subsequent updates shall be available via the Internet for GSFC review and approval as part of the PMPCB process.

11.12.3 As-Designed Parts List (ADPL)

After CDR, when the designs have been finalized, the Parts database is updated to reflect the actual parts and quantities selected for the design. The ADPL shall be available via the Internet and submitted electronically to GSFC in accordance with contract requirements.

11.12.4 As-Built Parts List (ABPL)

The ABPL is an update to the ADPL with additional as-built information, such as the manufacturers name, part number and lot date code. The ABPL shall be available via the Internet and submitted electronically to GSFC in accordance with contract requirements.

11.13 Alerts

The LM Team shall be responsible for review and disposition of Government Industry Data Exchange Program (GIDEP) Alerts for applicability to the parts proposed for use. In addition, any NASA Alerts and Advisories or Lockheed Martin Mission Success Bulletins shall be reviewed and dispositioned. Alert applicability, impact, and corrective actions shall be documented and be made available for GSFC review. Section 15 of this plan describes the Lockheed Martin alert system implementation.

11.14 Additional Requirements

11.14.1 Traceability

Lockheed Martin's existing Parts, Materials and Process (PMP) database provides the capability to retrieve historical records of EEE parts from initial procurement and receipt through, storage, kiting, assembly, test, and final acceptance of the deliverable product. When parts are received, they are assigned a Receiving Control Number (RCN). The RCN is recorded in the build documentation to permit the traceability to the procurement document and provide for:

- Cross-referencing and traceability of part manufacturer and date code to the assembly traveler or production plan.
- Traceability to the date code or manufacturer's inspection lot or wafer lot (where applicable). Traceability is maintained throughout manufacturing for each deliverable item

11.14.2 Prohibited Metals

Lockheed Martin has implemented a Prohibited Parts, Materials and Processes for Satellite Applications (2.3.5-T1-SpecEng-1.2-S) that prohibits the use of pure tin plating, cadmium, and zinc in addition to many other items based on company wide Best Practices.

11.14.3 PCB Supplier and Manufacturer Surveillance (Monitoring)

Lockheed Martin's Procurement Quality organization maintains surveillance and auditing of suppliers, vendors, laboratories and manufacturers to ensure compliance to procurement, quality, and technical requirements. Any PMPCB concerns with suppliers and manufacturers shall be coordinated with Lockheed Martin's Procurement Quality organization for action and resolution.

11.14.4 Reuse of Parts and Materials

Parts and materials, which have been installed in an assembly, and are then removed from the assembly for any reason, shall not be used again in any item of flight or spare hardware without prior approval of the Material Review Board and the PMPCB.

11.15 Data Requirements

Lockheed Martin will make Attributes (parametric test) summary available to GSFC for all testing performed upon request. Variable data (read and record) shall be recorded for initial, interim and final electrical test points. Test data shall be available to GSFC upon request.

For those parts potentially susceptible to radiation effects in the HRV environment, a summary radiation report that identifies parameter degradation behavior shall be provided to the PCB. Variable data acquired during radiation testing shall be available to GSFC upon request.

11.15.1 Retention of Data and Test Samples

The LM Team has methods in place for retention of data generated for parts tested and used in flight hardware. The data is kept on file in order to facilitate future risk assessment and technical evaluation, as needed. In addition, Lockheed Martin and subcontractors shall retain all part functional failures, all destructive and non-flight non-destructive test samples, which could be used for future validation of parts for performance under certain conditions not previously accounted for. PIND test failures may be submitted for DPA, radiation testing or used in engineering models. Parts and data shall be retained in accordance with contract requirements.

11.15.2 End Item Acceptance Package

Lockheed Martin has implemented a process for Item Technical Data Packages (2.3.6-T1-DesEng-1.0-P-W4) that defines the minimum deliverable requirements for completed configuration items and the responsible organizations for preparing the inputs. This process enables flow-down of additional program deliverable requirements. For HRVDM/HDV, the requirements of DID 1-2 shall be implemented for in-house and all subcontractor and teammate flight deliverable items.

11.15.3 Photographic Requirements

The requirement for digital photographs will be incorporated into the fabrication planning and implemented during the build process by Product Assurance. The LM Team shall provide a digital photographic record of each electronic PWB and subassembly. The photograph shall be of sufficient resolution to clearly show component placement, part marking, or details that are covered or obscured at subsequent levels of assembly and/or any other operation that renders subsequent inspection impractical. Photographs shall also be provided of the end item clearly showing all critical details.

Each photograph shall be identified with a label containing the following information: assembly number, serial number, description (e.g., name of the assembly), date of photo, and the supplier's company name. The subject shall appropriately fill the digital frame to allow for effective magnification. The image shall be of sufficient resolution to permit identification of components and verification of wire routings. The resolution shall also permit further enlargement of the image if required for analysis.

Photographic images shall be a minimum 6.0 Mega pixel digital image file. A complete set of photographs shall be included in each end item data package.

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12 MATERIALS SELECTION

Lockheed Martin's PMPCB process has been used successfully on previous NASA programs

- Web-based PMPCB process and associated materials and processes lists were developed and implemented on A2100 program
- Subcontractor listings incorporated into on-line database
- Real time database with remote access facilitates IPT/subcontractor/GSFC interface
- On-line non-standard materials approval request form streamlines tracking and approval process

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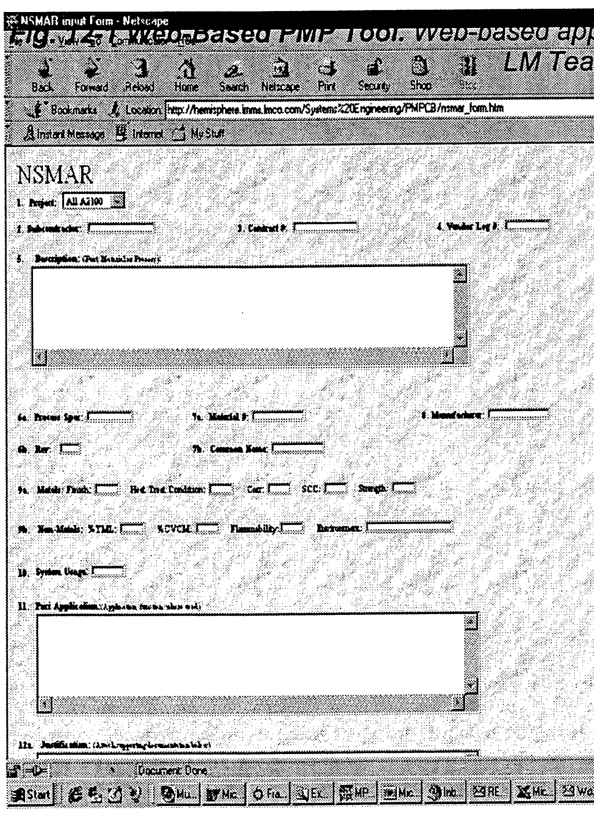
The LM Team shall implement a Parts, Materials and Process Control Board (PMPCB) process that has been used successfully on previous NASA programs. For HRVDM/HDV the process makes extensive use of Internet based databases to provide seamless access among Lockheed Martin team members, subcontractors and GSFC. Subcontractor material and process (M&P) requirements are flowed down via a separate M&P document that is implemented in the statement of work (Fig. 12-1).

12.1 General Requirements

A Parts, Materials, and Processes Control Plan (PMPCP) shall be prepared and released for use on the HRVDM/HDV Project after contract award. The PMPCP shall define requirements for the identification, selection, standardization, and control of mechanical parts, materials and processes. The PMPCP is utilized at the preliminary design phase of the project to minimize material problems during hardware development and subsequent operation, and continues through detailed design, hardware build, and test. The requirements of this plan are applicable to all hardware built by the Lockheed Martin team. The selection and control of all Parts, Materials, and Processes (PMP) shall take into consideration all properties required for each material usage for successful application of the part or hardware. Such properties include, but are not limited to, design allowables for structural and nonstructural hardware, fracture control and the detection of flaws, stress corrosion cracking, galvanic and general surface corrosion, galling, wear, cold welding, embrittlement phenomena, electromagnetic interference, electro static discharge, thermal vacuum stability, flammability, toxic offgassing, environments, and useful life.

Fig. 12-1. Web-Based PMP Tool: Web-based approval process streamlines communication between the LM Team and GSFC



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The HRVDM/HDV Materials Assurance Engineer (MAE) must concur with all PMP used for the spaceflight hardware.

12.2 Compliant Materials

Compliant PMP shall be used in the fabrication hardware to the extent practicable. In order to be compliant, a material must be used in a conventional application and meet the applicable selection criteria identified below. A conventional application or usage of a material is the use of compliant materials in applications in which there is spacecraft heritage in identical or similar applications. Compliant materials meet the following applicable selection criteria:

1. Hazardous materials requirements, including flammability, toxicity and compatibility as specified in NASA-STD-6001.
2. Vacuum outgassing requirements as defined in Section 12.2.4.
3. Stress corrosion cracking requirements as defined in Marshall Space Flight Center MSFC-STD-3029.

12.2.1 Non-Compliant Materials

A material that does not meet the above requirements, or meets the requirements, but is used in an unconventional application, will be considered to be a non-compliant material. The proposed use of a non-compliant material requires that a Materials Usage Agreement (MUA) or PMPCB approved equivalent form be submitted to the GSFC MAE for approval. The HRVDM/HDV program will make use of an Internet based form as shown in Fig. 12-1 to facilitate the review and approval process.

Non-compliant materials are reviewed for approval on the basis of: similarity, analysis, test, inspection, existing data, or a combination of these methods and also to insure that they meet the applicable requirements of this document.

12.2.2 Polymeric Materials

As part of a web-based Materials Identification and Usage List (MIUL), the polymeric materials and composites are available for GSFC review/approval in accordance with DID 12-1. Material acceptability is determined on the basis of flammability, toxic offgassing, vacuum outgassing, ESD effects and all other materials properties relative to the application requirements and usage environment.

12.2.3 Flammability and Toxic Offgassing

Material flammability and toxic offgassing shall be determined in accordance with the test methods described in NASA-STD-6001. Payload materials shall meet the requirements of EWR 127-1 Range Safety Requirements.

12.2.4 Vacuum Outgassing

Materials are selected and/or preconditioned to eliminate the possibility of introducing detrimental levels of molecular contamination to critical surfaces. In general only materials that have a total mass loss (TML) less than 1.00% and a collected volatile condensable mass (CVCM) less than 0.10% when tested in accordance with ASTM E-595 will be approved for use in a vacuum environment. The Materials Engineer will use the reference documents and databases below when evaluating selected materials for compliance to HRVDM/HDV requirements.

- MSFC-HDBK-527/JSC 09604, or the MAPTIS database that forms the basis for the MSFC-HDBK-527/JSC 09604 document.
- MSFC-SPEC-1443 provides outgassing data on a limited number of materials.
- GSFC Reference Publication 1124 is a database of outgassing data

- JSC 08962 is a significant volume of outgassing data.
- GSFC 740-SPEC-008 Appendix B contains metals ratings and nonmetallic materials acceptable for outgassing and flammability.
- STR-29, HST Servicing Mission Contamination Control Requirements

The PMPCB may require lot specific testing for those materials suspected of having lot variations (e.g., paints, epoxy, etc.). In such cases, material approval for each lot is contingent upon the test results. The PMPCB may also address concerns with materials that meet the screening criteria described above, but are of concern because of the location the material is used, the source and receiver temperatures fluctuate or large amounts of the material are used. Any issues the PMPCB is unable to resolve at its level will be elevated to the Project for resolution.

If material outgassing rates need to be established at source and receiver temperatures other than those specified in ASTM E-595, the MOLEKIT facility at GSFC or an equivalent facility approved by GSFC shall be used.

12.2.5 Shelf-Life-Controlled Materials

Polymeric materials that have a limited shelf-life are controlled by a process that identifies the start date (manufacturer's processing, shipment date, or date of receipt, etc.), the storage conditions associated with a specified shelf-life, and expiration date. Materials such as o-rings, rubber seals, tape, uncured polymers, lubricated bearings and paints shall be included. The use of materials whose date code has expired requires that the LM Team demonstrate by means of appropriate tests that the properties of the materials have not been compromised for their intended use. The LM Team shall submit affected applications for shelf life extension to GSFC for review and approval prior to implementation. When a limited-life piece part is installed in a subassembly, the subassembly item is included in the Limited-Life List and is subject to GSFC MAE approval.

12.2.6 Inorganic Materials

A web-based inorganic materials usage list is a part of the MIUL and is available for GSFC review and approval in accordance with DID 12-2. The criteria specified in MSFC-SPEC-3029 are used to determine that metallic materials meet the stress corrosion cracking criteria. The HRVDM/HDV program will make use of an Internet based form as shown in Fig. 12-1 to facilitate the review and approval process of material usage that does not comply with MSFC-STD-3029. Lockheed Martin will provide supporting application data for any material usage to the GSFC MAE upon request.

Lockheed Martin has implemented a Prohibited Parts, Materials and Processes for Satellite Applications (2.3.5-T1-SpecEng-1.2-S) that prohibits the use of pure tin plating, cadmium, zinc as well as many other items based on company wide Best Practices. The use of silicones shall be restricted in accordance with 2.3.5-T1-SpecEng-1.2-S and GSFC's requirements including no usage in direct line of sight with HST or more than 1 kg total usage.

12.2.7 Fasteners

Flight fasteners on HRVDM/HDV are tracked on the web-based MIUL and their usage approved as part of the PMPCB process. Flight fasteners shall comply with the procurement documentation and test requirements for flight hardware and critical ground support equipment fasteners contained in GSFC 541-PG-8072.1.2. With PMPCB approval, the screening requirements in existing SCDs or AIDs are used after evaluating the SCD/AID against the requirements of GSFC 541-PG-8072.1.2.

12.2.8 Lubrication

A web-based lubricant usage list shall be part of the MIUL and be available for GSFC review and approval. Supporting applications data will be made available to the GSFC MAE upon request. The vapor pressure of selected lubricants shall be reviewed as part of the PMPCB process relative to GSFC requirements (i.e., less than or equal to 10-7 Torr at + 40 C TBR).

12.2.9 Process Selection

The MIUL shall contain a Section listing all the manufacturing processes used on flight hardware. The list shall be available electronically for HST MAE review and approval. A copy of any process shall be submitted for review upon request.

12.2.10 Procurement Requirements

12.2.10.1 Purchased Raw Materials

Procured raw materials shall be accompanied by the results of any nondestructive testing performed such as ultrasonic testing for metals, chemical composition, and physical or mechanical tests, or a Certificate of Compliance verifying compliance to the procurement specification. Lot traceability shall also be required. This applies to all materials whether structural or non-structural. This information need only be provided to GSFC when there is a direct question concerning the material's flightworthiness.

12.2.10.2 Raw Materials used in Purchased Products

Suppliers shall meet the requirements of 12.2.10.1 and provide, upon request, the results of acceptance tests and analyses performed on raw materials.

13 CONTAMINATION CONTROL REQUIREMENTS

13.1 General

Developing contamination requirements early in the design phase is fundamental to meeting HRVDM/HDV performance. Our iterative approach to contamination requirements analysis as shown in Fig. 13.1-1 ensures compliance with mission requirements using a thorough evaluation of contamination sources, critical surfaces, and environments, use of extensive modeling tools (Fig. 13.1-2), and early mitigation measures. We also leverage our HST experienced contamination engineering staff located in Greenbelt Maryland throughout the design and build process to minimize contamination risks to HST.

These preliminary requirements aid design, material, and process selections before changes become more costly. These requirements are updated concurrently with design.

13.2 Contamination Control Verification Process

The LM Team implements a contamination control verification process as part of the systems engineering program as follows:

1. Determination of contamination sensitivity
2. Determination of a contamination allowance
3. Determination of a contamination budget
4. Development and implementation of a contamination control plan.

13.3 Contamination Control Plan (CCP)

An HRVDM/HDV System Contamination Control Plan shall be developed and submitted to GSFC for approval. At PDR, the HRVDM/HDV CCP defines and documents the cleanliness levels derived for all critical surfaces and subsystems from design through on-orbit operations. Acceptable outgassing levels at the mission operations level are determined and include items such as plume impingement, total long-term outgassing fluence and propulsion system compatibility. The Contamination Control Engineer shall form and lead the HRVDM/HDV Contamination Control Working Group to access and resolve contamination concerns at earliest design phases through launch and mission operations.

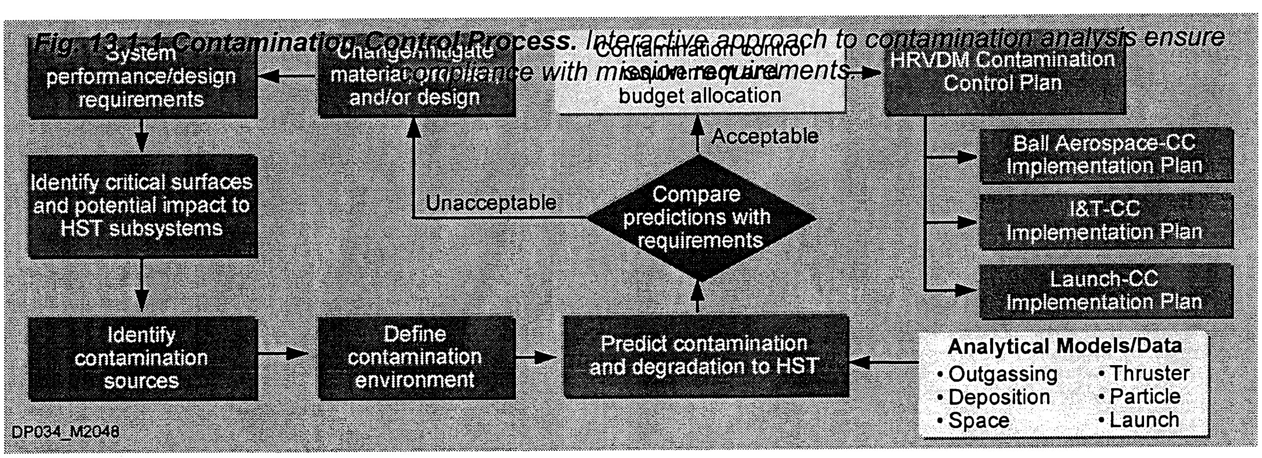

Fig. 13.1-1 Contamination Control Process. *Interactive approach to contamination analysis ensure compliance with mission requirements.*

Fig. 13.1-2 Contamination Analysis Tools. Extensive modeling tools ensure thorough evaluation.

Model	Function
Molecular Contamination	
MOLFLUX	• Direct and reflected fluxes (Line-of-sight contamination • Return Flux • Diffusion Limited Outgassing Rates Decay Over the Life of the Mission (1/Time)
Thermal Desktop	• Provides Source and Critical Surface Temperatures • Provides Viewfactors From Critical Surfaces to Spacecraft Outgassing Sources
MOLTRAN	• Launch Vehicle Molecular Outgassing (Based on Titan experience)
Particle Contamination	
PRTDIST	• Launch Vehicle Particle Redistribution (Based Titan and Atlas Experience)
On-Orbit Particle Redistribution Model	• Computes particle trajectories and determines intersections with spacecraft surfaces
Spacecraft Plumes	
PIDYN (Plume Impingement Dynamics)	• Plume flowfield, pressure, heating mass flux
GAMBIT (Grid Generator)	• Creates Geometric model of spacecraft thrusters and surfaces

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At CDR, Subsystem Contamination Control Implementation Plans include details on site-specific contamination controls, cleanliness verification, processes, thermal vacuum bake-outs, packaging, handling, and contingency plans. The Contamination Control Engineer is part of the review process for drawings, shop orders, and test procedures.

By being fully integrated with the Systems Engineering organization, the Contamination Engineer ensures the designs address issues such as particle generation, vent paths, and plume impingement.

13.4 Material Outgassing

Materials are screened and/or tested to assure low outgassing characteristics as noted in Section 12.2.4 of this plan. In addition, the design and control methods will ensure that the long-term outgassing fluence to the HST AB vents of material condensable at -20 C is less than 1e-6 g over science mission life.

13.5 Thermal Vacuum Bakeout

Thermal vacuum bake-outs of hardware at the lowest component level practical are done to prevent contamination of critical surfaces during ground test and on-orbit operation. The Contamination Control Engineer reviews all bake-out procedures to ensure that the parameters (e.g., temperature, duration, out-gassing requirements, and pressure) are correct for the hardware and meet the contamination allowance defined in the CCP. Outgassing verification using quartz crystal microbalance (QCM) analyses shall be performed during thermal vacuum testing as required.

13.6 Hardware Handling

In order to meet and maintain HRVDM/HDV cleanliness requirements, the Contamination Control Engineer shall implement the following:

- Institute cleanroom facility and associated protocol requirements for all HRVDM/HDV operations and tests including; integration in a class 100,000 or better cleanroom and cleaning of sub-assemblies prior to their becoming inaccessible as described in STR-29.
- Establish monitoring schedules for airborne and fallout particulate, molecular residue fallout, and hardware witness sampling.

- Train personnel in cleanroom operations, hardware cleaning, and HRVDM/HDV-specific handling controls.
- Develop and use customized covers and purge ports that allow access and/or cooling of subsystems during I&T yet minimize surface exposure.
- Apply proven and documented optical and thermal control surface cleaning procedures and packaging protections.
- Ensure packaging and handling controls are compatible with HRVDM/HDV cleanliness and ESD requirements.
- Perform surface cleanliness verification for particle and molecular residue at established I&T phases for optical, thermal control, and payload fairing surfaces. At a minimum, external surfaces shall be Visibly Clean Highly Sensitive per STR-29.
- Develop contingency plans that provide mitigation measures for contamination control violations or problems before they arise during I&T operations.

The full details of hardware handling required by the MAR shall be provided in the CCP.

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14 ELECTROSTATIC DISCHARGE CONTROL (ESD)

- Meet requirements of ANSI/ESD-S20.20
- ESD procedures are addressed facility wide
- Existing procedures control all aspects of hardware life cycle
- Only trained individuals handle electronic hardware
- ESD Control Plan is built upon most stringent contracts requirements

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Lockheed Martin has documented and implemented an ESD Control Program that assures that all manufacturing, inspection; testing and other processes do not compromise mission objectives for quality and reliability due to ESD events. The Lockheed Martin ESD Control Program is a facility wide program designed to meet requirements and conditions imposed by a broad range of contracts. The Lockheed Martin ESD Program is audited both internally and by Customers verifying compliance with requirements

Lockheed Martin's ESD Control Program has been proven effective on numerous NASA, DoD, and commercial programs

14.1 Applicable Documents

Lockheed Martin's ESD Control Program is fully compliant with ANSI/ESD-S20.20. Lockheed Martin imposes ESD controls regardless of the contractual requirements by the standard procedure—EN 01.01 "Electrostatic Discharge (ESD) Control program.

The requirements of the ESD control program are implemented through MP 75025, Protection of Static Sensitive Devices. ESD Training is implemented in AP 04.18.

14.2 ESD Requirements

Lockheed Martin's ESD Control Program shall be suitable to protect the most sensitive component involved in the project. As part of the design process, parts are reviewed for ESD sensitivity with the intent of eliminating or reducing the number of those that are determined to be extra-sensitive (0 to 300 Volts). MP75025 provides the required controls to be implemented when processing such hardware items.

The Lockheed Martin ESD procedures noted previously fully address training, protected work area procedures and verification schedules, packaging, facility maintenance, storage, and shipping. All personnel who manufacture, inspect, test, otherwise process electronic hardware, or require unescorted access into ESD protected areas shall be trained prior to handling any electronic hardware. Required training and certification is defined and implemented in accordance with Lockheed Martin's ESD Control Program and detailed process documentation. Training and certification records are maintained in the Lockheed Martin Data Systems.

Lockheed Martin's ESD Control Program ensures that electronic hardware are manufactured, inspected, tested, or otherwise processed only at designated ESD protective work areas. These work areas are verified on a regular schedule as identified in the Product Assurance & Systems Safety Standards.

Lockheed Martin's ESD Control Procedures ensure that electronic hardware are properly packaged in ESD protective packaging at all times when not actively being manufactured, inspected, tested, or otherwise processed.

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15 GIDEP AND PROBLEM ADVISORIES

- Provide single point of contact across programs and businesses
- Multifunctional review board ensures technical depth and oversight of process
- Internal bulletin process enables early identification of problems and lessons learned to be communicated across business areas, subcontractors and programs
- All alerts and internal bulletins are Internet accessible by IPT members

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Lockheed Martin is a full participant in the Government-Industry Data Exchange Program (GIDEP) in accordance with the requirements of the GIDEP S0300-BT-PRO-010 and S0300-BU-GYD-010.

The Mission Success organization is the single point of contact within Lockheed Martin for receiving, distributing, and initiating GIDEP data and documents.

Lockheed Martin also maintains an internal "Bulletin" system to identify problems or lessons learned with particular parts, materials or processes from across the corporation. Figure 15-1 demonstrates the process flow for GIDEP and Mission Success Bulletins within the corporation. The process requires closed loop feedback of disposition actions taken by all programs as well as generation of the appropriate GIDEP document when required.

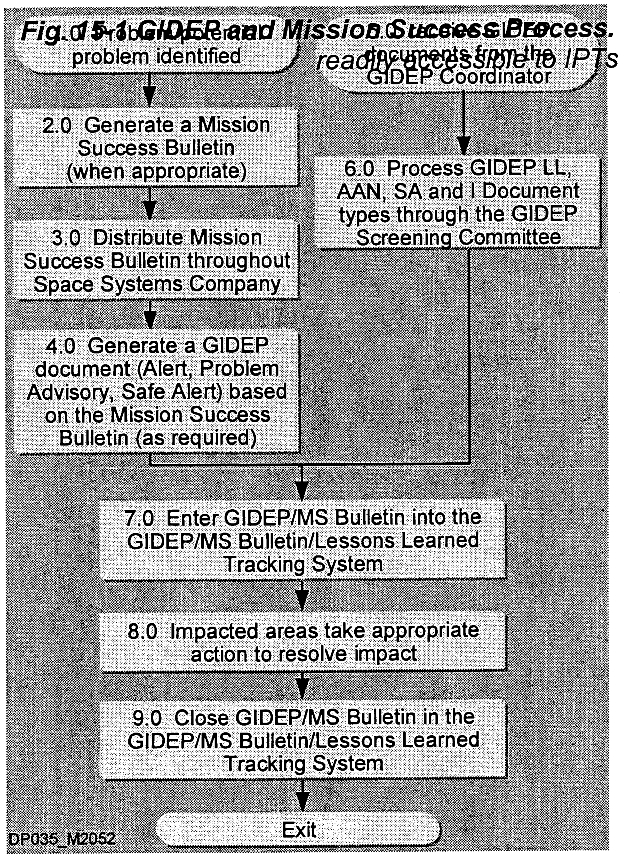

Fig. 15-1 GIDEP and Mission Success Process. *Our GIDEP/Bulletin process is a closed loop system readily accessible to IPTs via web-based application.*

An Anomaly Experience Review Board (AERB) is convened on an as needed basis by Lockheed Martin specialty engineering to review systemic anomalies. The AERB, includes management membership from Parts Engineering, Materials and Processes Engineering, Product Assurance, and Procurement. The Board supports the technical assessment of all released GIDEP alerts/bulletins that are distributed to the Programs, Product Centers, and functional areas for responses.

In addition to the distributed GIDEP Alerts and Problem Advisories, all other GIDEP documents are reviewed at a biweekly screening committee meeting for relevance and distribution to the programs, product centers, and functional areas

Lockheed Martin's Mission Success Organization responsible for alert process implementation

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APPENDIX 1 APPLICABLE DOCUMENTS

Document No.	Title
ANSI/ASQC Q9000-3	Quality Management and Quality Assurance Standards – Part 3: Guidelines for the Application of ISO 9001 to the Development, Supply and Maintenance of Software
ANSI/ISO/ASQ Q9001:2000	American National Standard Quality Systems - Model for Quality Assurance in Design, Development, Production, Installation and Servicing
ANSI/ESD S20.20	ESD Association Standard for the Development of an Electrostatic Discharge Control Program for protection of electrical and electronic parts, assemblies, and equipment (excluding electrically initiated explosive devices).
ANSI/IPC-A-600	Acceptability of Printed Boards.
ASTM E-595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
EWR 127-1	Eastern and Western Range Safety Requirements
FAR	Federal Acquisition Regulations
GEVS-SE	General Environmental Verification Specification for STS and ELV Payloads, Subsystems and Components.
GMI 1700.2	Goddard Space Flight Center Health and Safety Program
GPG 8621.2	Processing Mishap, Incident, Hazard, and Close Call Reports
GPG 8621.3	Mishap, Incident, Hazard, and Close Call Investigation
GPG 8700.4	Technical Review Program
GPG 8700.6	Engineering Peer Reviews
GSFC S-312-P003	Procurement Specification for Rigid Printed Boards for Space Applications and Other High Reliability Uses
GSFC EEE-INST-002	Instructions for EEE Parts Selection, Screening, and Qualification and Derating
IEEE STD 610.12	IEEE Standard Glossary for Software Engineering Terminology
IEEE STD 730	IEEE Standard for Software Quality Assurance Plans
IEEE STD 982.2	IEEE Guide for the Use of IEEE Standard Dictionary of Measures to Produce Reliable Software
IPC A-600	Acceptability of Printed Boards
IPC-A-610	Acceptability of Electronic Assemblies
IPC D-275	Design Standard for Rigid Printed Boards and Rigid Printed Board Assemblies
IPC/EIA J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies
IPC-2221	Generic Standard on Printed Board Design
IPC-2222	Sectional Design Standard for Rigid Organic Printed Boards
IPC-2223	Sectional Design Standard for Flexible Printed Boards
IPC-6011	Generic Performance Specifications for Printed Boards
IPC-6012	Qualification and Performance Specification for Rigid Printed Boards
IPC-6013	Qualification and Performance Specification for Flexible Printed Boards
IPC-6018	Microwave End Product Board Inspection and Test
ISO 17025	General Requirements for the Competence of Testing and Calibration Laboratories
JSC 26943	Guidelines for the Preparation of Payload Flight Safety Data Packages and Hazard Reports
KHB 1710.2	Kennedy Space Center Safety Practices Handbook
MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-470	Designing and Developing Maintainable Products and Systems
MIL-HDBK-472	Maintainability Prediction
MIL-STD-461	Electromagnetic Emission and Susceptibility Requirement for Control of Electromagnetic Interference
MIL-STD-756	Reliability Modeling and Prediction
MIL-STD-1629	Procedures for Performing a Failure Mode Effects and Criticality Analysis

Document No.	Title
MSFC CR 5320.9	Payload and Experiment Failure Mode Effects Analysis and Critical Items List Ground Rules
MSFC-HDBK-527	Material Selection List for Space Hardware Systems
MSFC-SPEC-522	Design Criteria for Controlling Stress Corrosion Cracking
NASA RP-1124	Outgassing Data for Selecting Spacecraft Materials
NASA RP-1161	Evaluation of Multilayer Printed Wiring Boards by Metallographic Techniques
NHB 8060.1	Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion
NPD 8700.1	NASA Policy for Safety & Mission Success
NPD 8710.3	NASA Policy for Limiting Orbital Debris Generation
NPG 7120.5	NASA Program and Project Management Processes and Requirements
NPG 8000.4	Risk Management Procedures and Guidelines
NPG 8715.3	NASA Safety Manual
NASA-STD-2100-91	Software Documentation Standard
NASA-STD-2201-93	Software Assurance Standard
NASA-STD-2202-93	Software Formal Inspections Standard
NASA-STD-6001	Flammability, Odor, Off-gassing and Compatibility Requirements & Test Procedures for Materials in Environments that Support Combustion
NASA-STD 8719.13	NASA Software Safety Standard
NASA-STD 8719.14	Guidelines and Assessment Procedures for Limiting Orbital Debris
NASA-STD-8739.1	Workmanship Standard for Staking and Conformal Coating of Printed Wiring Boards and Electronic Assemblies
NASA-STD-8739.2	Workmanship Standard for Surface Mount Technology
NASA-STD-8739.3	Workmanship Standard for Soldered Electrical Connections
NASA-STD-8739.4	Workmanship Standard for Crimping, Interconnecting Cables, Harnesses and Wiring
NASA-STD-8739.5	Workmanship Standard for Fiber Optic Terminations, Cable Assemblies and Installation
NSS 1740.13	NASA Software Safety Standard
NSS 1740.14	Guidelines and Assessment Procedures for Limiting Orbital Debris
NSTS 14046	Payload Verification
NSTS 22648	Flammability Configuration Analysis for Spacecraft Applications
NSTS/ISS 13830	Payload Safety Review and Data Submittal Requirements
NSTS/ISS 18798	Interpretations of NSTS/ISS Payload Safety Requirements
S-302-89-01	Procedures for Performing a Failure Mode and Effects Analysis
S-311-M-70	Specification for Destructive Physical Analysis
SAE AS9100	Aerospace Standard, Quality Systems Model for Quality Assurance, Design, Development, Production, Installation and Servicing
SAE JA1002	Software Reliability Program Standard
540-PG-8715.1.1	Mechanical Systems Division Safety Manual – Volume I
540-PG-8715.1.2	Mechanical Systems Division Safety Manual – Volume II
541-PG-8072.1.2	GSFC Fastener Integrity Requirements
5405-048-98	Mechanical Systems Center Safety Manual